

Restoring Meanders to Straightened Rivers

1.1 New meandering channel through open fields

RIVER COLE

LOCATION - COLESHILL, (OXON/WILTS BORDER) SU234935

DATE OF CONSTRUCTION - AUTUMN 1995

LENGTH - 500m

COST - £9,000

Figure 1.1.1

PLAN OF UPSTREAM OF MILL



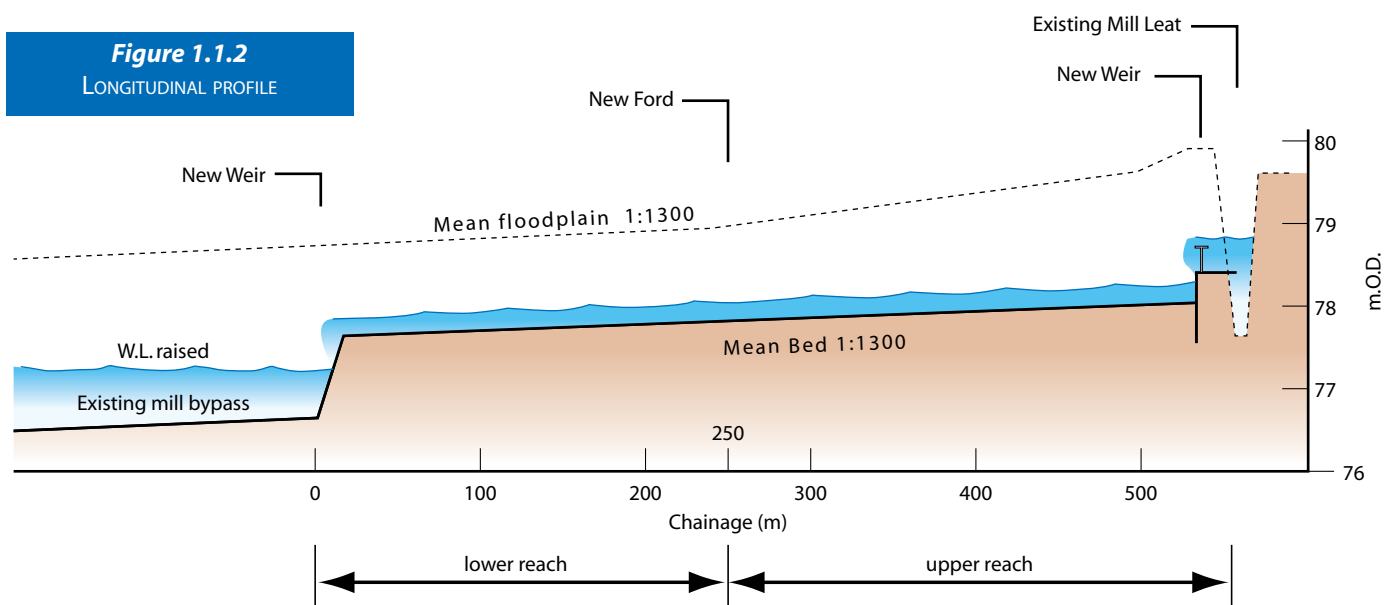
Lower reach in Summer – August 1997

Description

A new river course was created to introduce a reach of free flowing water to a floodplain that hitherto featured only a slow flowing mill leat. An existing mill by-pass channel remained in operation and was incorporated into the new design by extending it as far upstream as practical to create the additional meandering channel that was required. The River Cole is now diverted from the leat to flow in the new channel, which is small in size, to ensure seasonal inundation of the adjacent floodplain.

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Figure 1.1.2
LONGITUDINAL PROFILE**Design***Longitudinal profile (Figure 1.1.2)*

The new mean bed gradient was set at 1:1300 to match the mean floodplain gradient. The bed elevation was set to give the shallowest channel possible whilst having just sufficient depth to contain summer spates. The resultant channel bed is elevated higher than the old mill by-pass, but is lower than the retained water level in the mill leat which feeds it. Drop weirs were therefore required at each end (see *Techniques 5.1 and 5.2*).

Whilst weirs are generally undesirable, the alternative of deeper channels was more so at this site. The drop at the downstream end was reduced in height as a consequence of introducing new meanders downstream of the mill; these raised normal water level in the existing mill by-pass to historic levels (see *Technique 1.2*).

Upper reach at time of excavation – October 1995



Upper reach – 1998





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Alignment of channel (Figure 1.1.1)

The existing mill by-pass follows an ancient course of the River Cole. Remnants of its ancient course were also evident in the fields between chainage zero and 250m, (lower reach), so the new channel was set to follow these at a fairly uniform depth of c. 1m. Upstream of ch. 250m the new channel deviates from any natural course because it had to be aligned roughly parallel to the mill leat which is unnaturally close to the edge of the floodplain. Land levels along this upper reach rise significantly above the average for the floodplain, hence the new channel is deeper. Meanders were set out to 'mimic' the natural form evident in the lower reach.

Cross-sections (Figures 1.1.3 – 1.1.4)

Section A shows a normal flow channel 2.6m wide by 0.8m deep - the geomorphology of the Cole indicates this to be the ideal size of channel. Because overall channel depth needed to exceed 0.8m (Figure 1.1.2). The upper banks were graded back as flat as practical.

Figure 1.1.3

SECTION A THROUGH SYMMETRICAL CHANNEL

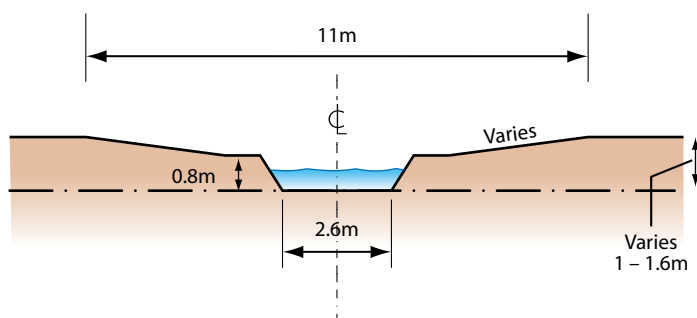
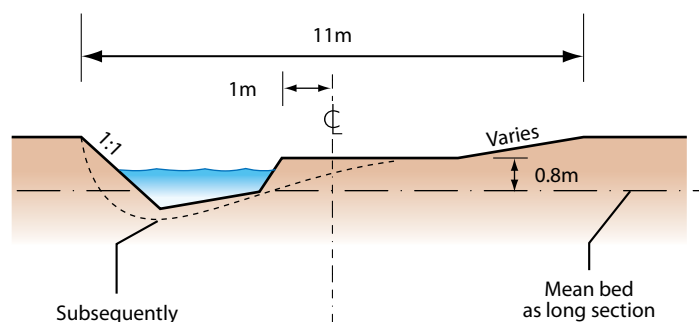


Figure 1.1.4

SECTION B THROUGH SYMMETRICAL CHANNEL



Subsequent performance 1995 – 2001

The upper reach of the channel developed an intermittent bed substrate of gravel as well as small riffles of gravel below each meander. Limited supplies of gravel are derived from the clays exposed towards the bottom of the channel; none are carried down from the upper catchment. Additional gravels were imported to this reach one year after construction and 'seeded' into each pool for distribution by flood currents.

In the lower reach, where the new channel is less deep, gravels are less evident throughout. The drop weir at the lower end draws water noticeable faster as it approaches it. Downstream of this structure, the old by-pass channel has attracted substantial deposits of gravel, sand and silt derived from the new channel. These deposits are well sorted and have partially restored bed levels/profiles in the by-pass to historic levels, recreating variable flow depths.

The stiff clays in the river banks resisted erosion preventing cliffs from forming on the outside of meander bends where 1:1 batters were cut. Conversely, floodwaters were racing across the flat areas formed on the inside of each meander causing scour of the surfaces. The asymmetrical profiles were subsequently re-excavated as indicated on Section B.

Since these modifications the channel has performed satisfactorily in all respects; a good range of flow currents, substrates and bank forms are sustained throughout the year.

No planting, or seeding of the channel was undertaken. Natural colonisation is occurring slowly. The channel is unfenced allowing cattle access at low density under Countryside Stewardship prescriptions. Cattle have effectively grazed a proliferation of willow seedlings. Both aspects are being monitored.

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© Environment Agency

The new meandering river course and the restored meander in the mill leat (see 1.3) – July 1997
Photo: Environment Agency



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1.2 New channel meandering either side of existing channel

RIVER COLE

LOCATION - COLESHILL, (OXON/WILTS BORDER) SU234935

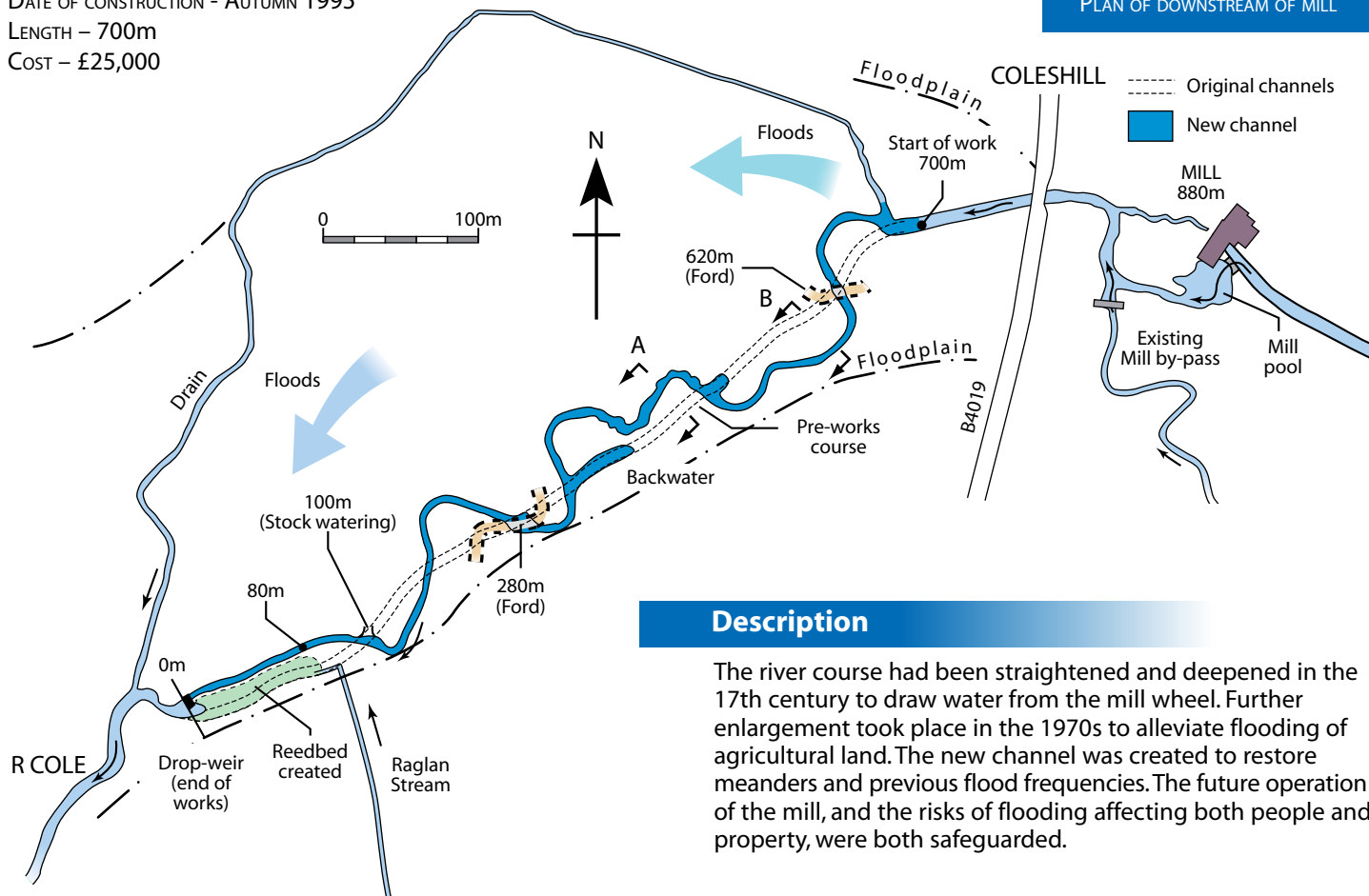
DATE OF CONSTRUCTION - AUTUMN 1995

LENGTH - 700m

COST - £25,000

Figure 1.2.1

PLAN OF DOWNSTREAM OF MILL



Description

The river course had been straightened and deepened in the 17th century to draw water from the mill wheel. Further enlargement took place in the 1970s to alleviate flooding of agricultural land. The new channel was created to restore meanders and previous flood frequencies. The future operation of the mill, and the risks of flooding affecting both people and property, were both safeguarded.



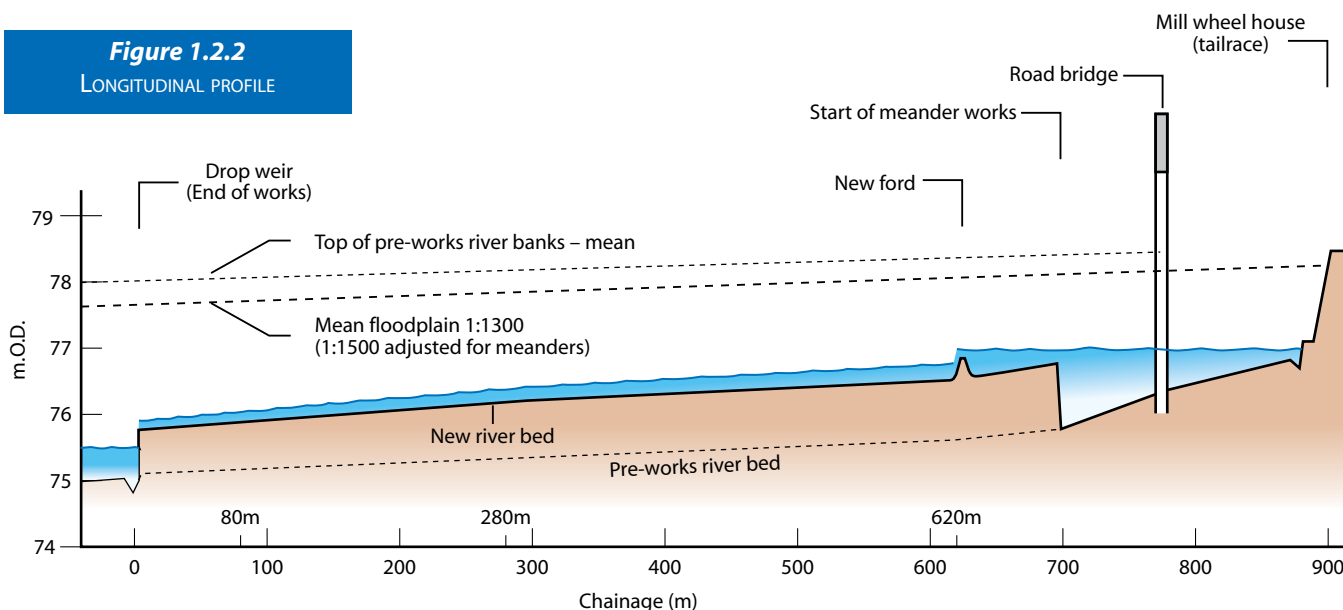
Aerial view of new meanders - July 1996

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Figure 1.2.2

LONGITUDINAL PROFILE

**Design***Longitudinal profile (Figure 1.2.2)*

The elevation of the new river bed was raised by up to 1.0m, the maximum possible that still enabled water to flow freely from the old mill wheel tailrace. The bed gradient would ideally have paralleled that of the mean floodplain gradient (1:1300 straight; 1:1500 meandered) but was steepened to reduce the height of the drop structure needed at the downstream end of the reach. The actual bed gradients constructed are: chainage 0-280m at 1:740; 280-620m at 1:1000; 620-700m at 1:460; these equate to a mean of 1:700.

The raised bed enabled impoundment of water upstream of the works, restoring historic levels in the mill pool and the mill by-pass. A stone ford was built at ch. 620m to safeguard water levels against any downward scour of the new bed.



Channel before works – 1994



New channel flowing into existing channel during construction – September 1995



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Meanders during construction – 1995

Alignment of channel (Figure 1.2.1)

Practical influences on the meander layout were the desire to retain several mature willows on the new river banks, and to maintain a sensible balance of land areas lost/gained either side of the old straight course. A geomorphological audit of the river, including a study of meander form evident in the downstream reach, finalised the layout. The relatively straight reach between ch. 0 and 80m avoided disturbing a fritillary meadow alongside and facilitated a riverside reedbed downstream of the Raglan Stream junction (see Part 9). At ch. 280m the meander deliberately cut into rising ground just off the floodplain to provide a local cliff face c. 2.5m high.

Cross-section (Figures 1.2.3 – 1.2.4)

Section A shows a normal flow channel 2.6m wide by 0.8m deep. The geomorphological audit of the Cole indicates this to be the ideal size of channel. Because actual channel depths were greater than 0.8m, the upper banks were graded back at shallow profiles.

Section B shows a compatible asymmetrical section introduced at each bend. The deepest bed level is below the mean bed gradient to ensure that pools are sustained.

Land profiles between meanders

These were all lowered by c. 0.4m to levels that approximated to the mean floodplain levels (Figure 1.2.2).

This necessitated the removal of spoil deposited on the old river banks from the 1970s deepening works. The conveyance of flood flows across the meanders proved to be important in achieving the necessary hydraulic safeguards during 1 in 100 year flood conditions.

Figure 1.2.3

SECTION A THROUGH ASYMMETRICAL CHANNEL

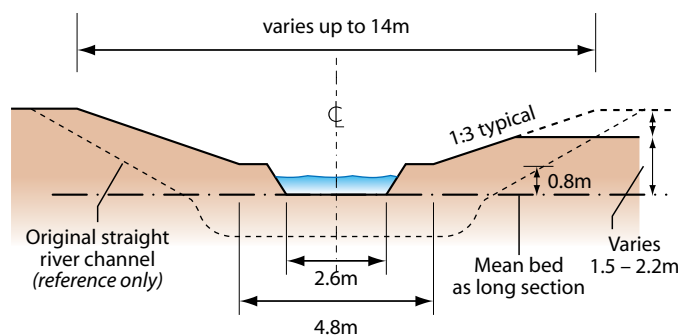
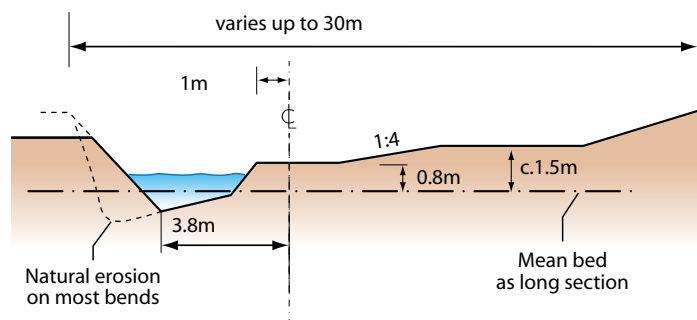


Figure 1.2.4

SECTION B THROUGH ASYMMETRICAL CHANNEL



The old straight channel located within these areas was largely backfilled, although not completely (see Parts 2 and 8 for details of backwaters, fords, stock watering points, etc that were incorporated).

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Subsequent performance 1995 – 2001

Spates of floodwater immediately following completion of the new channel led to rapid and extensive reshaping of the channel. Cliffs were eroded, pools were scoured and gravel riffles and sandy shoals deposited, all creating desirable natural features within the reach. Excess sediments built up immediately downstream of the works, helping to restore a further reach of the original over-deep channel. Since these initial adjustments, subsequent spates have satisfactorily sustained the regime

described but at a much lower rate of change. Intervention has been limited to further flattening of the profile of the inside of the south side bend at ch. 280m. The river is largely unvegetated after two summers, although marginal vegetation is becoming established. A wide range of soil types are exposed in the channel and these account for the diversity of features that are now evident.



Diverse new channel
– Two years after
construction.
– March 1997



Natural cliff formation
post works – March 1997



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1.3 New meander in an impounded river channel

RIVER COLE

LOCATION - COLESHILL, OXON/WILTS BORDER, SU234935

DATE OF CONSTRUCTION - AUTUMN 1996

LENGTH - 300m

COST - £9,000

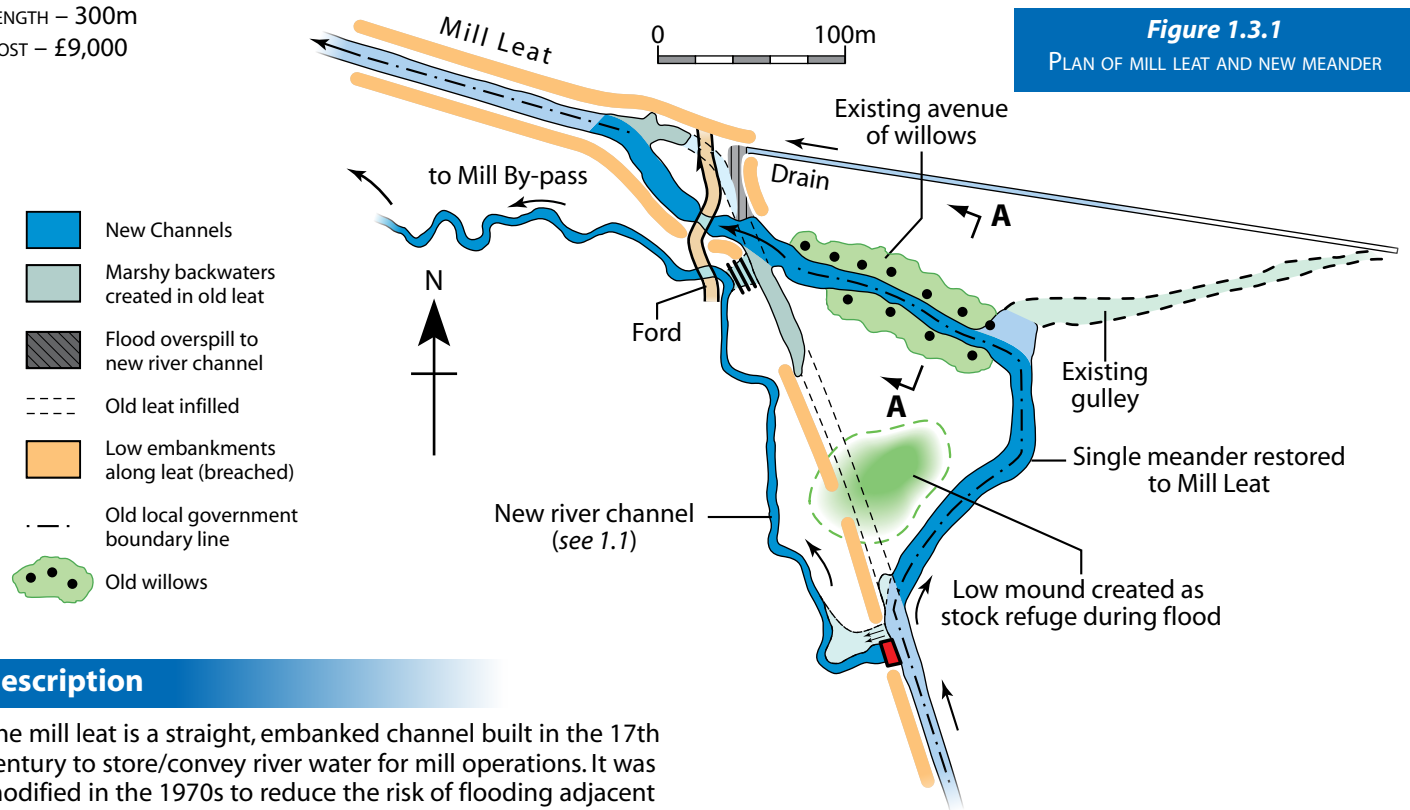


Figure 1.3.1

PLAN OF MILL LEAT AND NEW MEANDER

Description

The mill leat is a straight, embanked channel built in the 17th century to store/convey river water for mill operations. It was modified in the 1970s to reduce the risk of flooding adjacent land. As part of the River Cole restoration project most of the river flow now by-passes the mill (and the leat) in a new meandering channel (see *Technique 1.1*). The leat was subsequently enhanced by restoring a single meander to its course.

Design

Longitudinal profile

The existing river bed levels were retained throughout the new meander in order to maintain the historic depths of impounded water. Normal water levels were raised by c. 300mm to achieve this, involving replacing/repairing sluices at the mill in accordance with archived drawings retained by the owner, the National Trust. No embankments were reinstated on the new meander; water is free to spill into adjacent fields consistent with the overall river restoration objectives for this site.

Alignment (Figure 1.3.1)

The pre-existence of the meander was evident in two ways. A shallow, muddy depression between a short avenue of old willow pollards, branching off the leat, delineated part of an old river channel. A study of old maps indicated that an historic local government boundary line passes between the willows, continuing in a clear meander line that rejoined the leat further upstream. This line was adopted as the centre line of the new meander because of the strong precedence.

Cross-section (Figure 1.3.2)

The width of channel between bank tops was selected to retain the willows. The resulting dimensions closely matched the top width of the remaining mill leat, so was confirmed as suitable. The existing leat cross-section displayed wide ledges at, or about, normal water level that were cattle trodden either side of a deep, relatively clear, central channel. The new cross-section mirrors this configuration.

Profiles within the meander

The way in which flooding of surrounding land had been designed to occur makes livestock escape or rescue difficult. In mitigation, land levels within the new meander were raised locally in a gentle mound creating a refuge in times of flood.

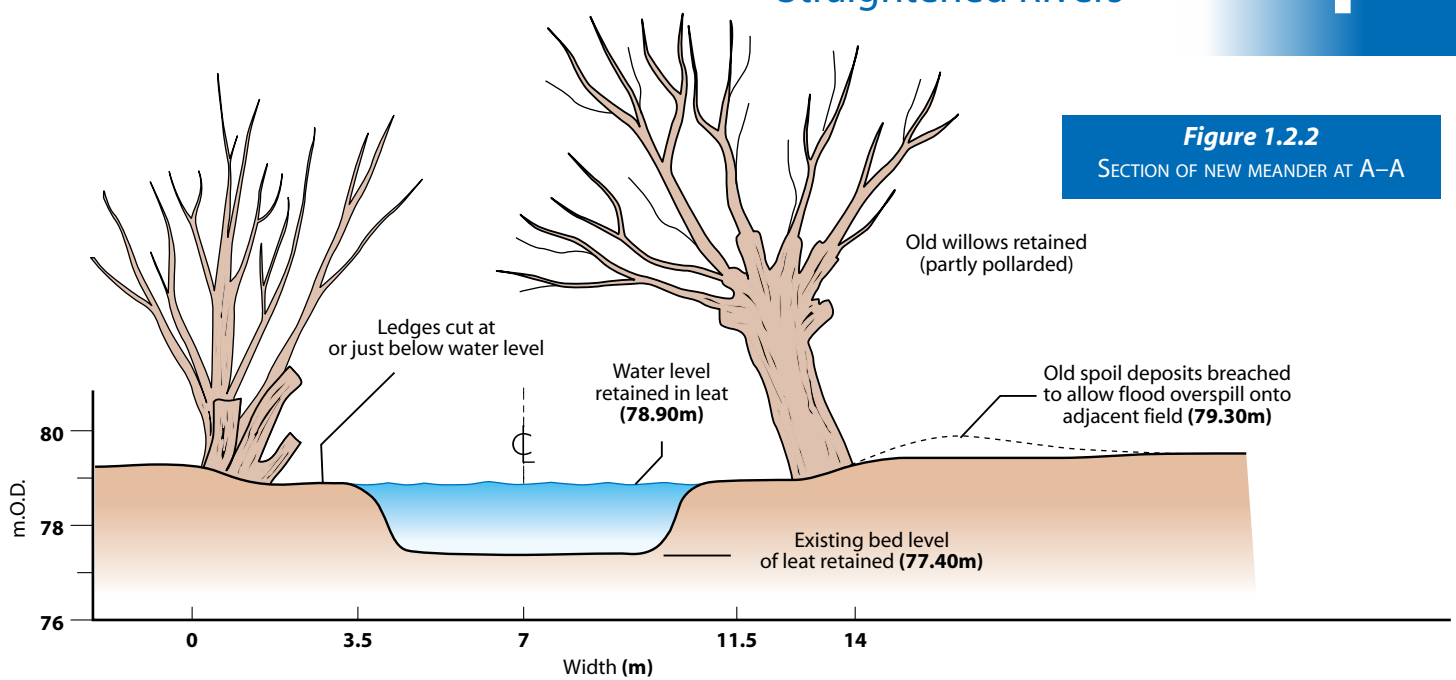
Subsequent performance 1995 – 2001

The new meander is visually striking between the willows; swans nested on the spit of land between the new and old channel where a quiet backwater has been created. Sheep are seen to favour the mound, being the 'highest and driest' ground in the area regardless of flooding. Marginal plants are satisfactorily establishing on the ledges each side of the newly created channel.

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Figure 1.2.2
SECTION OF NEW MEANDER AT A-A



Remnant of meander
– pre-works – January 1996
(shallow water held temporarily after heavy rain/flooding).



Re-excavated meander
– Autumn 1997



Restoring Meanders to Straightened Rivers

1.4 New meanders to one side of existing channel

RIVER SKERNE

LOCATION - DARLINGTON, Co DURHAM, NZ301160

DATE OF CONSTRUCTION - AUTUMN 1995 TO SPRING 1996

LENGTH - 500m

COST - £40,000

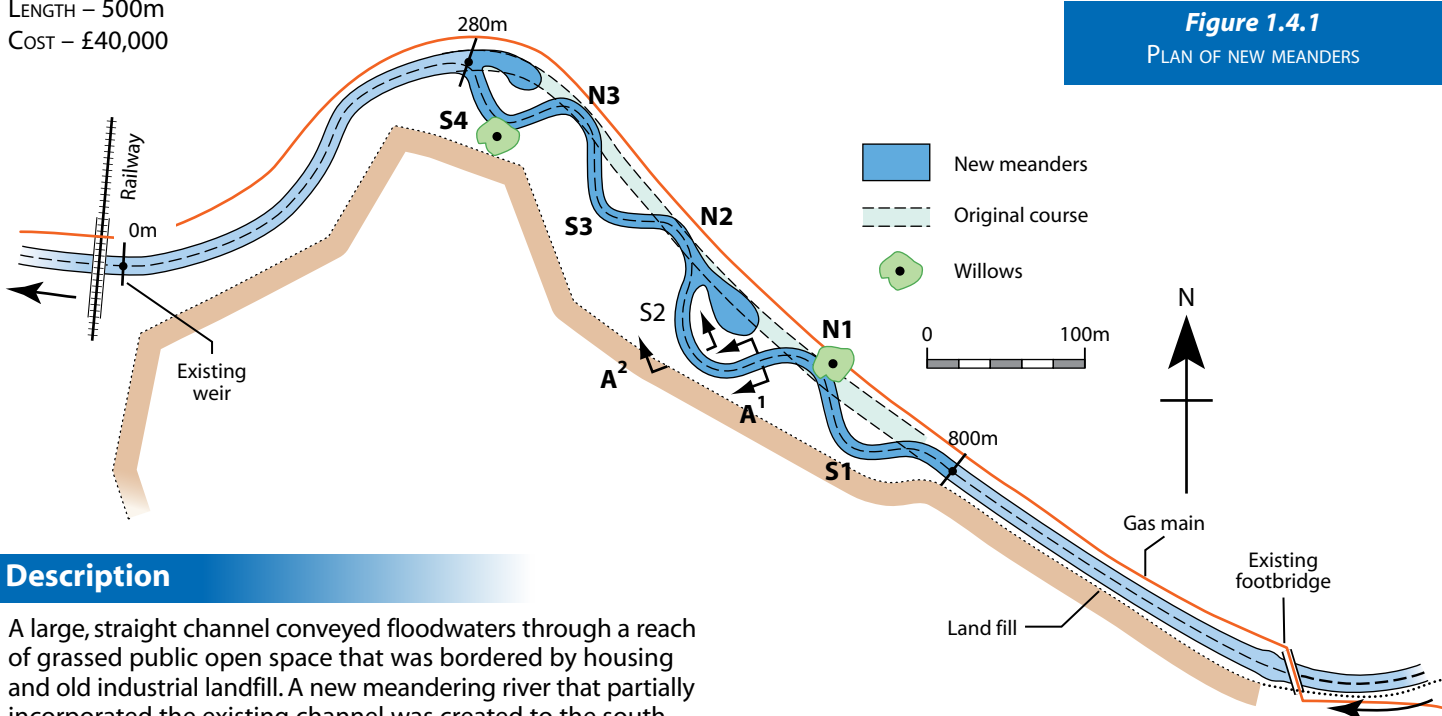


Figure 1.4.1
PLAN OF NEW MEANDERS

Description

A large, straight channel conveyed floodwaters through a reach of grassed public open space that was bordered by housing and old industrial landfill. A new meandering river that partially incorporated the existing channel was created to the south side. The risk of flooding, affecting people and property, was safeguarded.



© Northumbrian Water/AirFotos

Meander excavation
- Autumn 1995

Design

The original mean bed gradient of 1:1300 paralleled the mean bank gradient at a depth of c. 2.4m. The new mean bed gradient and level matches the existing but flattens to 1:1500 because of the increased length created. meander was expected to reach c. 1m depth as observed at an existing bend at ch. 1200m. This is shown as 'lowest bed' on the long section 1m below mean bed. Conveyance of floodwaters across the new meanders was facilitated by a general lowering of inter-meander land levels by c. 0.6m. This also enhanced water storage aspects of the 1 in 100 year flood hydrograph, attenuating the peak flow downstream.

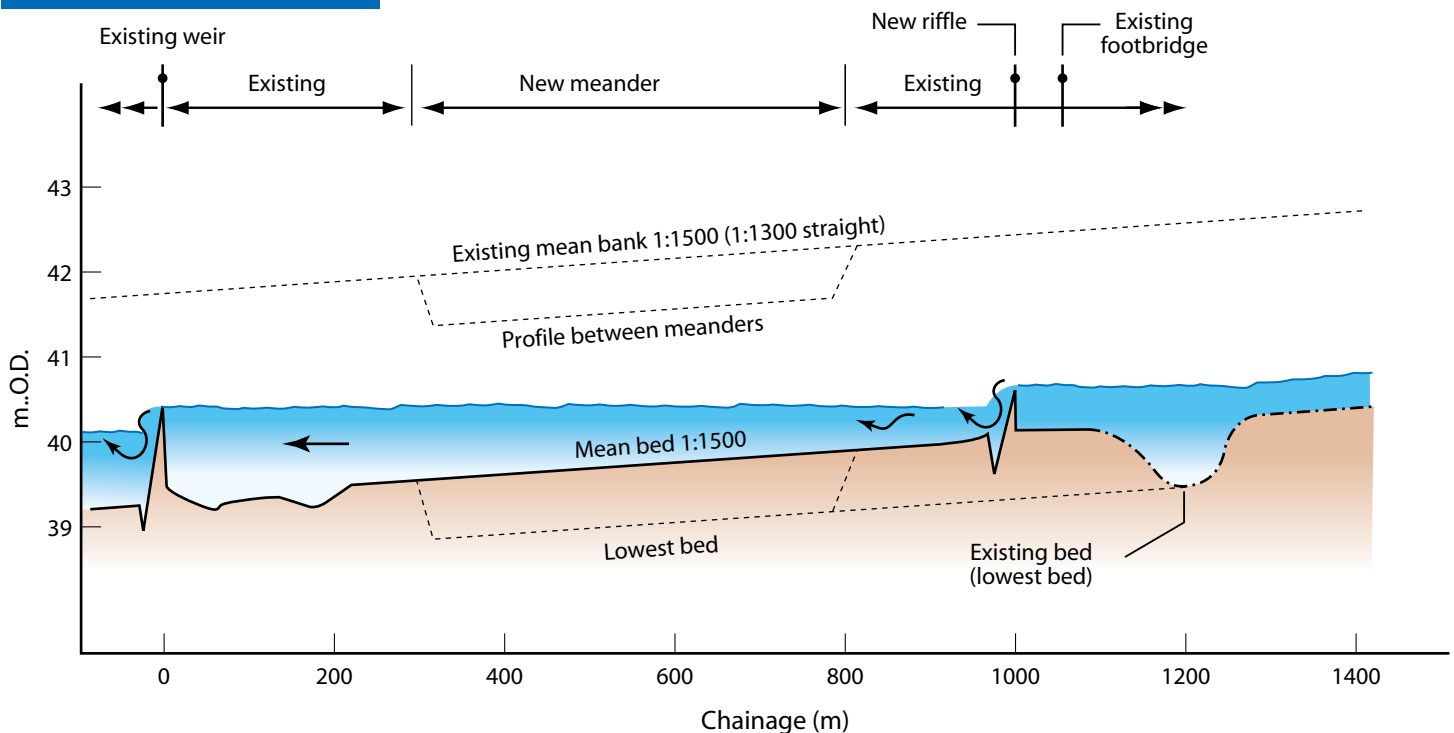
Normal water levels in the reach are controlled by an existing weir at ch. 0m, but the effect of this diminished at ch. 900m where the original straight channel was retained and enhanced. Enhancements included an artificial rock/gravel riffle at ch. 1050m shown on the long section (see Part 3).

Alignment of channel (Figure 1.4.1)

The lateral extent of meandering is constrained between a gas main, running closely alongside the north bank of the old course, and landfill tipped to within 10 to 50m of the south straits precluded any possibility of 'mirroring' historic mean

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Figure 1.4.2
LONGITUDINAL PROFILE

bank. Bends **S4** and **N1** were located to retain two mature willows on the banks. The remaining meanders are set out between and checked against geomorphological criteria to finalise the layout. High flows in this channel and other constraints precluded any possibility of 'mirroring' historic meander patterns that were sustained by entirely different hydraulic criteria.

Cross-sections (Figure 1.4.3)

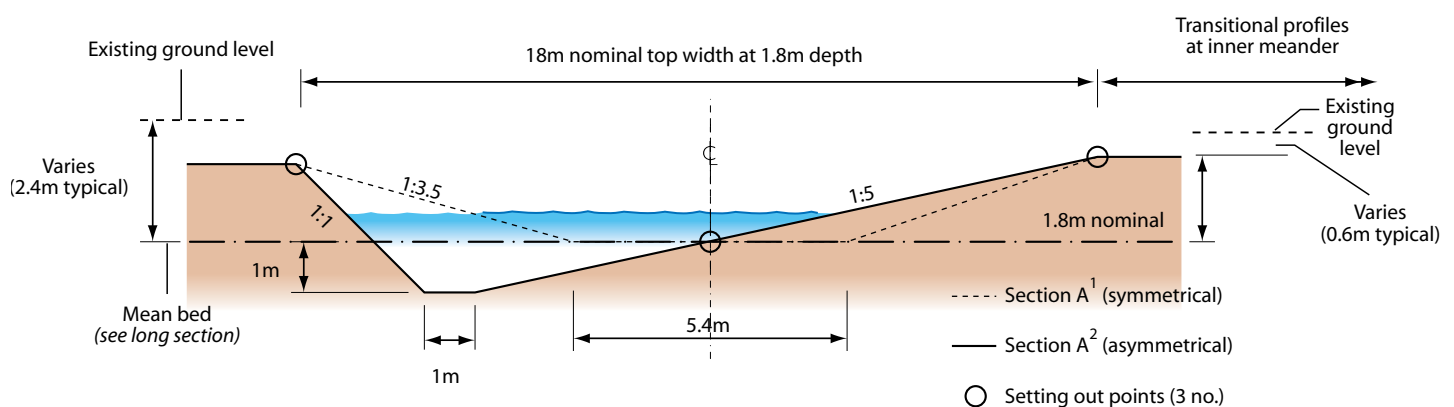
Because of continuously varying vertical depths described for the longitudinal profile, the design needed to be simplified. Two sections (symmetrical and asymmetrical) were developed based on mean depth (1.8m) and mean top width (18m). These applied to two points only on each meander - intermediate

profiles required a continuous transition between them. The asymmetrical section allows for 1m of scour at each bend described above.

A variation of the pair of sections shown was developed for bends **S1** and **S4**. A horizontal ledge at normal water level was incorporated around the inside of each to simulate the effects of natural shoaling.

Profiles within meanders (see Techniques 6.2 and 2.1)

As well as the general lowering of land levels described above, considerable profiling was specified to ensure inundation in time of flood was progressive from the downstream leg back towards the start of each meander. Similarly, special consideration

**Figure 1.4.3**
SECTION THROUGH NEW MEANDERS

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was needed to ensure the safe 'submergence' of backwater features prior to general overbank flow. The safety of people during rising floods is of particular importance at this urban location. Exceptionally, land within bend **N1** could not be significantly re-profiled as a high voltage cable passes underneath.

the indigenous clays have resisted erosion. Sands, silts and mud have deposited as shoals where eddy currents arise around the inner margins of bends and the deeper pools created around the outside appear self-sustaining. Diverse flora and fauna have rapidly colonised the many different features of the new course and local people enjoy relatively safe access to the waters edge.

The newly meandered channel has proved to be stable under frequently occurring flood conditions. The most vulnerable banks, located where bends are incorporated into the backfilled course, are supported by revetments (see *Part 4*), but elsewhere



Completed meanders
– Summer 1997



Looking downstream
towards large backwater
– February 1997

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1.5 New meandering channel replacing concrete weirs

RIVER MARDEN

LOCATION – Town centre at Calne, Wiltshire ST998710

DATE OF CONSTRUCTION – 1999

LENGTH – 100m

COST – not available

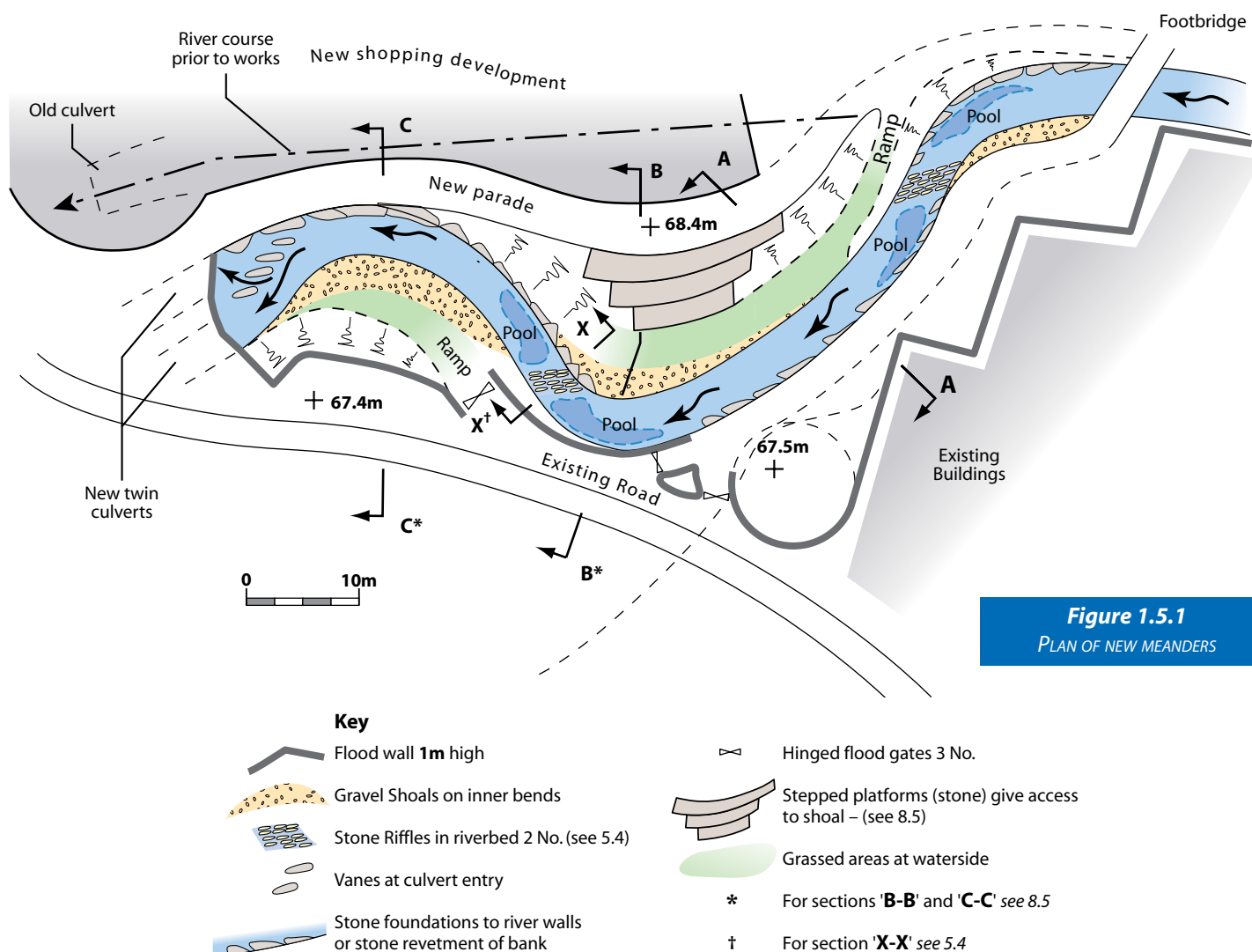


Figure 1.5.1
PLAN OF NEW MEANDERS

Description

A town centre factory had been demolished leaving a reach of river flowing through the site in a straight, concrete channel. The channel bed dropped vertically in two places forming weirs that barred the passage of fish and were unsightly.

Redevelopment of the site required that the river be diverted south of its existing course and that its character be improved to create an attractive public amenity. The site is prominently located in the heart of an ancient market town.

The diversion was undertaken in the form of a double meander such that natural geomorphological features including shoals, riffles and pools could be incorporated, as well as good public access to the waterside and a variety of sustainable attractive habitats for flora and fauna.

Earlier proposals to create an impounded, canal-like waterway were dropped in favour of the relatively free flowing river regime described.

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Design

The diversion necessitated the re-siting of the upstream part of twin box culverts that carry the river under the main road. *Figure 1.5.1* shows the location of old and new culverts. The double meander route between the existing channel and the new culverts was optimised within the constraints of the existing and new buildings shown.

The gradient of the new river bed became 'fixed' between the culvert invert and the existing upstream level. *Figure 1.5.2* shows the resultant longitudinal profile with a mean bed gradient of 1 in 140. This gradient is much steeper than arises naturally on this part of the river with consequent high water velocities when the river is in flood.

Hydraulic modelling indicated velocities of up to two metres per second and flood levels up to 0.8m above adjoining roads and property. These hydraulic parameters meant that flood walls would be needed to contain the river and that erosion of the river bed and banks would need to be rigidly controlled.

A design concept was needed that was sufficiently robust to meet these demanding hydraulic conditions but equally to meet the need for an attractive and sustainable environment.

The concept adopted was based on the premise that the gradient and alignment of the river were more typical of upland river locations where rock outcrops and gravel and cobble river bed substrates might be expected. Design of the many elements of the project began by developing a method of simulating stratified bedrock underneath the whole river

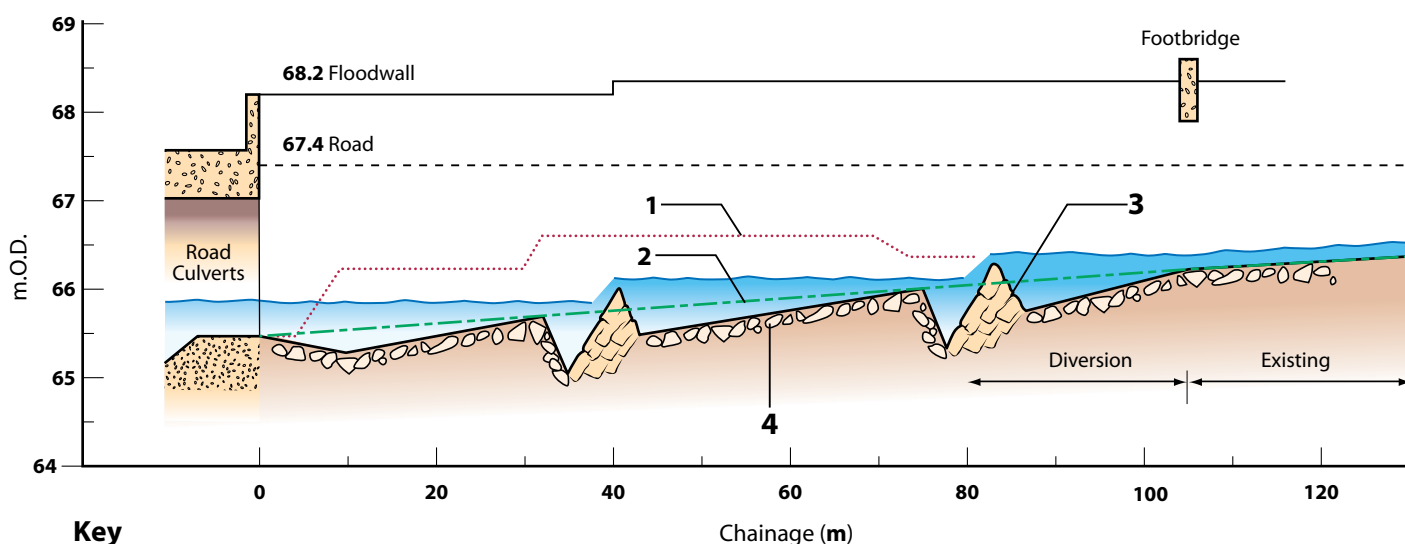
diversion that would 'outcrop' to form river bank revetments, retaining wall foundations and river bed control cills.

Research was undertaken to select quarried rock that could be re-constructed on-site to simulate its natural characteristics. Purbeck Limestone from quarries at Swanage was chosen because it occurred in large, flat slabs of thickness between 0.1m to 0.9m. Slabs of rock could be laid securely, one above another, at consistent angles to recreate the 'dip and strike' of natural outcrops. The stone was sufficiently durable to withstand frost and could also be provided in cut building blocks for use in walls. Its colour and texture is similar to locally available Cotswold stone but its durability was much greater, an important factor in riverside locations.

The following lists the key locations where stone slabs were incorporated:

Within the foundations of all vertical riverside retaining walls

Slabs were laid at a consistent angle to project into and above the water creating the appearance of the walls being built on natural rock. Contrasting faces on opposite sides of the river were achieved by maintaining the 'dip' in the same direction i.e. smooth dip slopes one side and jagged escarpment faces on the other. As the river alignment approaches the culverts in the same direction as the selected dip-slopes, slabs were laid with the dip parallel to the retaining wall. This enabled a series of 'craggy' current deflectors to be incorporated into the foot of the wall.



Key

- 1 Original bed level – concrete channel with two drop weirs
- 2 New mean bed gradient at 1 in 140
- 3 Two stone riffles built to stabilise river bed; pools upstream and downstream of each
- 4 Actual bed profile of gravel and cobble substrates

Figure 1.5.2
LONGITUDINAL PROFILE



Restoring Meanders to Straightened Rivers



Before:
View downstream towards culvert



Completion:
View of the new river course

At the bottom of earth slopes on outer bends liable to erosion
Slabs were laid exactly as above with consistent direction of dip and strike torevet these banks with varying faces depending upon the channel alignment of each location. See section A–A, figure 1.5.3 for aspects of both wall foundations and bank revetments.

Outcrops in the riverbed to create low cills

The steepness of the river bed gradient needed to be checked by introducing two low barriers of rock to resist any tendency of the bed to scour downwards. These are

shown as feature 3 on figure 1.5.2. They are located just downstream of each meander bend where underwater bars of river bed substrate e.g. gravels would naturally accumulate in the form of riffles. The stonework on adjacent walls and river bank was linked across the bed with stone laid at the same dip slope. Technique 5.4 shows details of these. They incorporate a gently sloping downstream face, much like a riffle. This enables the easy passage of migratory fish to be achieved and creates a 'tumbling' water feature rather than a sharp fall.

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Building stone in walls and for amenity surfaces

Dressed stone was used to face and cap all retaining walls and flood walls as well as the headwalls on the new road culvert. These headwalls were designed with curving arched soffits to give the appearance of an older stone bridge, hiding the unsightly concrete boxes that carry the water under the road. On the inner bend fronting the new development, large stone slabs were laid to create stepped platforms down to the waterside shoal (see 8.5 for details).

Vertical vanes in the river upstream of the new road culverts

The twin culverts create an artificially wide river channel at entry with the consequential risk of the culvert on the inside of the bend attracting excessive silt accumulations. Four upright slabs of stone were concreted into the river bed to induce a sustained flow of water towards the inner culvert without barring the natural tendency of flow towards the outer culvert. The slabs project a nominal 0.15m above normal water levels and serve as 'vanes' that effectively modify the water currents at all stages of river flow, including flood flows.

All of the stone features described effectively define a precise and stable course to the river which was essential in this tightly developed urban location. The creation of the river bed and waterside shoals was an equally important aspect of design since both had to be similarly stable as well as being able to sustain flora and fauna.

Geomorphological calculations were undertaken to determine size, shape and distribution of the river bed substrates that were to be introduced in the differing hydraulic conditions generated by the double meander channel configuration. Two sources of material were selected for use either singly or in combination.

Stone rejects from nearby limestone gravel pits were used on the river bed upstream of chainage 40m (the lower riffle) where water velocities were highest. Sizes ranged from 40mm to 200mm and shape varied between rounded gravels and cobbles to flat pieces of stone. Elsewhere 40mm graded and washed gravels were used where water velocities were less severe. This included the inner bend shoals where the public would have easy access. A mixture of both was used in intermediate locations simulating the natural 'grading' of bed substrates that would arise had they been carried and deposited by the river.

The design was completed to accommodate floodwalls and floodgates and a range of public access and amenity features as well as a comprehensive landscape planting scheme sympathetic to the riverine environment. The introduction of marginal aquatic plants, etc. along soft edges and within the numerous interstices of the rock outcrops was deferred until floodwaters has passed through the newly created reach of the river. This enables the river to modify and soften the engineered work thereby revealing the most appropriate plant species for the multitude of different habitat niches expected.

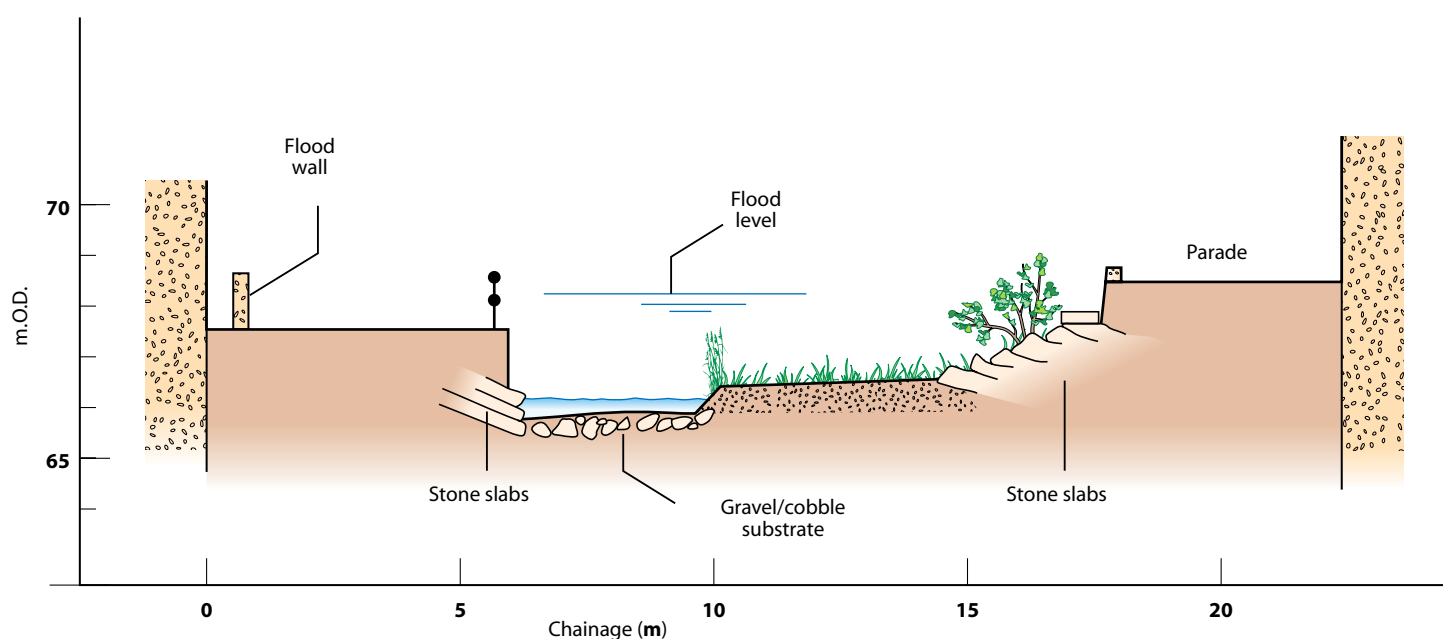


Figure 1.5.3

SECTION A THROUGH RIVER AND STONE SLABS



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Restoring Meanders to Straightened Rivers



View of Section A (*fig 1.5.3*) on completion



View of Section A in November 2001

Restoring Meanders to Straightened Rivers

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After: The new town centre in November 2001

Subsequent performance 1999 – 2001

The works have all remained remarkably stable bearing in mind that river bed substrates and shoal materials were all kept to minimum sizes, rather than 'over-sizing' to ensure stability.

The river has re-distributed some of the stone placed between the two riffles. This has created an additional riffle within the reach and the shoal at the front of the stepped platform has built up into an attractive, accessible beach.

The edge of the river channel between the two stone 'riffles' has slightly eroded along the un-revetted side. The latter can be easily controlled using pre-planted fibre rolls as part of the landscaping work and the former simply requires some gravel reject stone to be introduced into the soil that will then be grassed.

The four vanes at the culvert entry appear to be working well and sustain interesting current variations at low flows although some flood debris is attached to them. This debris is easily removed and is less problematic than it would be if it had entered the culverts.

The overall appearance of the riverworks is excellent and once the contractor finally clears the site and landscaping is completed it should naturalise well. Wildlife has occupied the site despite the intense building work with wagtails (*Motacilla spp.*), duck and fish being most obvious. The underwater rock and the sustained pools and faster flowing runs of water all promise to develop into valuable habitats.

Local comments are of young people enjoying 'messaging about in the river' with no serious vandalism, partly due to the robustness of the design concept.

Original Information Provider:
RRC



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1.5 River Marden 2013 Update

The pools and shoals have remained fixed as designed and some redistribution of the bed gravels that were introduced has occurred. Whilst there has been some movement of bed material into the left hand culvert this has not been excessive (see Figure 1.5.1).

Great care was taken to ensure the risk of movement from bed material was reduced. As such a geomorphologist was involved during the design stages of the project. Although there was initial concern from the Environment Agency about the introduced gravels moving and causing a maintenance problem at the mouth of the culvert. This has been shown not to be the case.

The new meandering channel has performed well with no repair and little maintenance required. The grass area is part of the focal point for the town and was designed to allow access. It has therefore been mown for landscaping and amenity more than would be recommended to achieve ecological benefits.

The flood walls have not breached since construction. The photograph below illustrates the additional flood capacity provided by the scheme.

This was a relatively expensive project but this high level of investment has had a major impact in raising the image of the high street as witnessed by its central hub function and visitor attraction. It is used as a postcard image and the town's publicity material frequently features the scheme.

As a result of the project, there has been an increase in the diversity of aquatic marginal vegetation with brown trout (*Salmo trutta*) now inhabiting the river through the town centre.



Restoring Meanders to Straightened Rivers

River Marden

WFD Mitigation measure

Medium energy, chalk

Managed realignment of flood defence
Removal of hard bank reinforcement/revetment, or replacement with soft engineering solution
Remove obsolete structure
Set-back embankments (a type of managed retreat)
Retain marginal aquatic and riparian habitats (channel alteration)
Sediment management strategies (develop and revise) which could include: substrate reinstatement, sediment traps, allow natural recovery minimising maintenance, riffle construction, reduce all bar necessary management in flood risk areas
Operational and structural changes to locks, sluices, weirs, beach control etc
Preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian zone

Waterbody ID

GB109053022060

Designation

None

Project specific monitoring

None

The river in flood – the flood gates are closed and the much increased capacity protects the town centre – November 2012

Restoring Meanders to Straightened Rivers

1



The designed channel and shallow grassed slopes hold up well over the winter period – early 2006

Mown green river edge to allow public access in summer.

Here the river's appearance is heavily managed as part of the aesthetics of the new town centre – 2010



Contacts

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Restoring Meanders to Straightened Rivers

1.6 Opening up a culverted stream

RIVER RAVENSBOURNE

LOCATION - NORMAN PARK, BROMLEY TQ412674

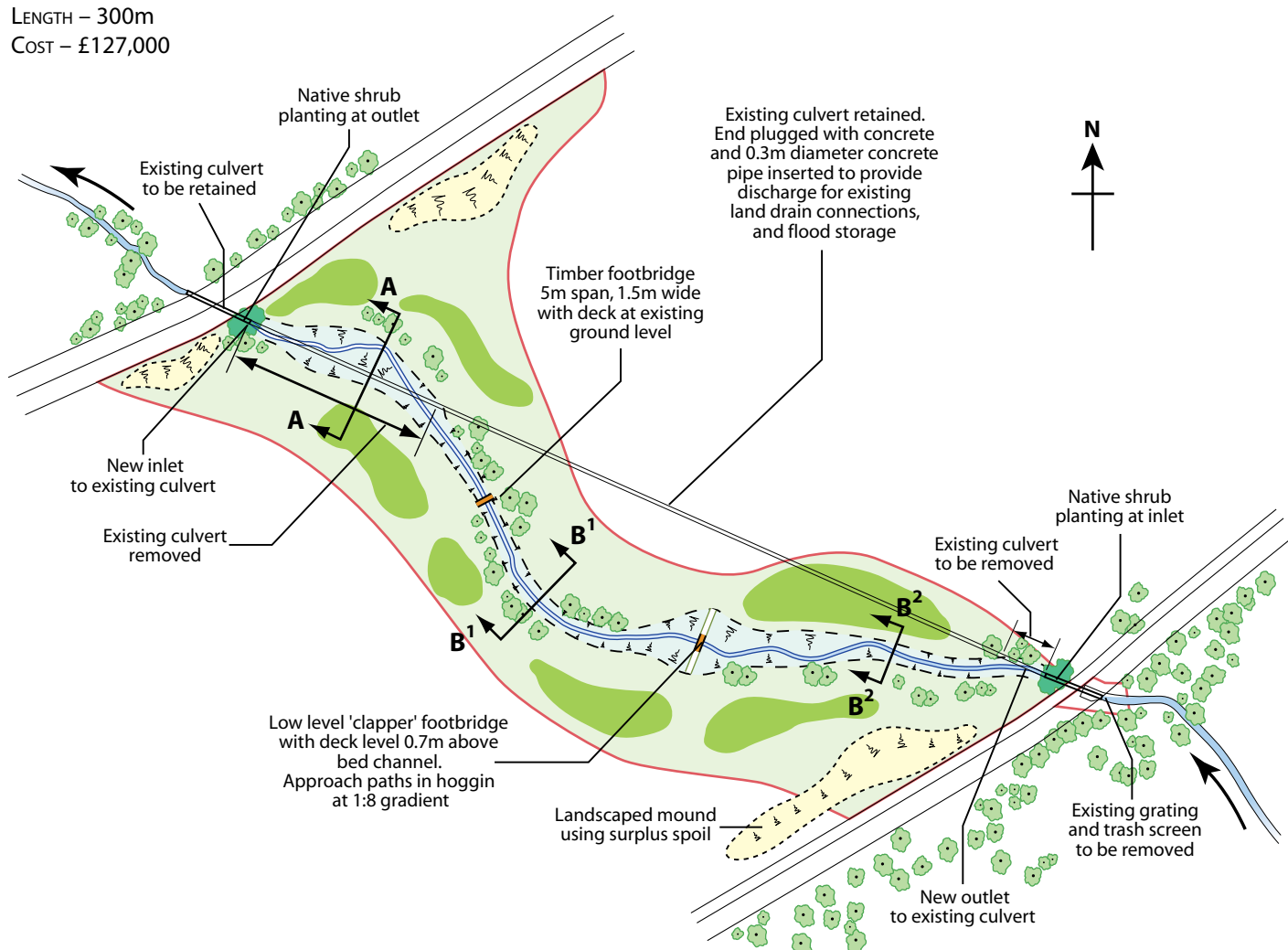
DATE OF CONSTRUCTION - MARCH TO JUNE 2000

LENGTH - 300m

COST - £127,000

Figure 1.6.1

PLAN OF NEW CHANNEL



Description

The Ravensbourne is a spring-fed stream flowing from its source near Keston, on the north slope of the North Downs, northwards through Bromley, Catford and Lewisham to join the Thames at Deptford Creek. In many areas such as Norman Park the stream was confined within a culvert.

Culverting of small watercourses in urban and parkland areas has been common in the recent past. Burying the river was felt to reduce the flooding potential, minimise safety issues associated with open water and maximise land available for development or use as open space/playing fields. Little consideration was given to habitat loss, aesthetic and landscape appeal of rivers or the potential benefits of surface water storage.

The Ravensbourne flowed for 300m through a 1m diameter concrete-lined steel culvert. Smaller land drains, which had been ditches before the area was levelled to form the park, flowed into the culvert at intervals along its length.

Park access tracks and major services, including a gas pipeline and electrical supply cables, crossed the culvert at the north end and a water pipe and local electrical supply cables at the southern end.

Deculverting (daylighting) this section of the Ravensbourne provided an exciting opportunity to restore a more 'natural' stream with diverse in-channel and bankside habitats that link with Scrogginhall Woods just upstream. It also provides an interesting recreational facility for the local public.

Restoring Meanders to Straightened Rivers

1



View of headscreen prior to removal



'Daylighting' of the Ravensbourne

Design

Financial justification for the scheme was threefold: reduction in costly maintenance for a culvert, the removal of a trash screen that also required regular clearing and was a safety issue, and an increase in flood storage. There was also a positive environmental gain.

The culvert was severed and approximately 70m of the 300m long culvert was removed, isolating 180m of the remaining section. Two short lengths were left to maintain the existing access track and service crossings. As the culvert was ruler straight, simply excavating the watercourse and removing the concrete would produce a far from natural channel. In addition, culvert removal, backfilling and reshaping is considerably more expensive than plugging and digging an alternative, though longer, course.

The design of the river channel was based on the historical layout, fluvio-geomorphology, flooding considerations and present day use of the park (cricket pitches). To avoid being overly prescriptive, the design drawings were kept relatively simple. The conditions encountered on site meant the final course is slightly different from the design plan (*Figure 1.6.1*). Indicative cross sections were provided at key locations with the main objective always a shallow, safe, accessible bank (*Figures 1.6.2 and 1.6.3*).

The new channel varied in bank slope and bed width, but followed a smooth longitudinal bed profile. By then infilling with an excess of gravel, the stream was allowed to shape its new bed, rather than 'constructing' pools and riffles.

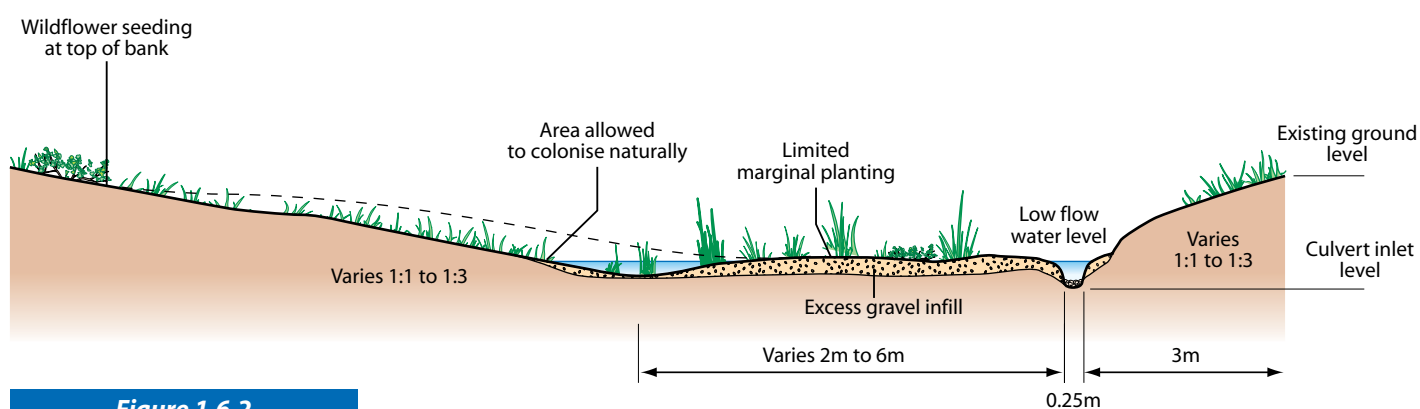


Figure 1.6.2

SECTION A THROUGH RAISED BED
AND MARGINAL SHOAL



Restoring Meanders to Straightened Rivers



Looking downstream at the shallow bank slopes. The severed culvert still visible



The new sinuous course and extent of wildflower seeding

The new course is 12.5% longer than the culvert, sinuous, with varying bed and top-of-bank widths. A shallow (1:8 batter) 'beach' area, as a result of an exposed gravel lens, and new meanders (1:5 inside batters) form the focal points for access to the stream.

When considering this type of scheme, where the stream emerges and then re-enters a culvert, it is good practice to build in 'sediment traps'. These can take many forms and do not have to resemble deep holes or even be maintained once the site has stabilised. At Norman Park the channel was greatly widened at the downstream end of the works forming a damp gravelly area which would act as a silt trap. This also allows the stream to find its own natural path within the confines of the overall channel width.

Spoil from the excavation remained on site, and the landscape architect located the mounds at either end of the new course, to ensure that they were subtle and blended into the park.

Two crossings have been constructed over the new channel, one a 'clapper' type bridge constructed of concrete (but looking like stone) and the other a timber structure. Both provide easy access across the stream and access to the water's edge is made possible along most of the course by shallow bank slopes.

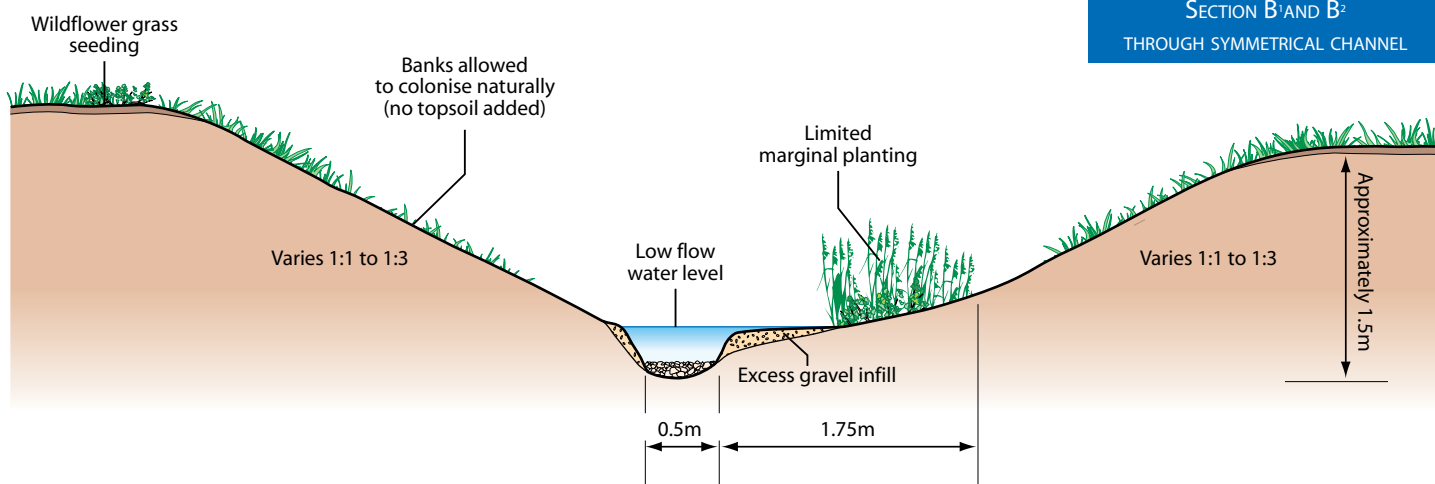


Figure 1.6.3

SECTION B' AND B"

THROUGH SYMMETRICAL CHANNEL

Restoring Meanders to Straightened Rivers

1

Planting up the 'wet berm' area and shielding the culvert entrance with shrub planting



Topsoil was not replaced on the riverbanks in order to attain a low fertility substrate suitable for the natural colonisation of wildflowers and plants from upstream. A 'buffer zone' between the amenity grassland and the top of the bank was seeded with a low-density wildflower mix from an approved source. This creates a visually pleasing edge to the playing fields and provides a suitable seed source for the banks. On the river's edge native provenance marginal plants were carefully sourced from a local nursery. School children were involved in some of the marginal planting. Wildflower plugs were also planted. The culvert entry and exit were both screened using a variety of native shrub species.

Subsequent performance 2000 – 2001

The park users, particularly dog walkers, now see the open Ravensbourne as a focal point, circling the area and making use of the crossing points. Children and dogs play along the banks even though the site has still to mature.

The gravel bed has been redistributed by the flow creating riffles and pools (down to the clay bed in places).



The marginal planting is suffering disturbance from early use and may take longer than expected to establish a good cover, though this should eventually produce a good diversity of edge habitats. The wildflower plugs have been decimated by crows in search of worms. About a third were removed from the ground and died.

The planting scheme was designed as a balance between creating an instant impact for the local users and allowing the natural processes of colonisation to occur. Even so the local users have stated that they would have liked more immediate impact from the planting.

Initial invertebrate and fish surveys have shown little change, but this should improve with time as the site matures and the marginal and emergent vegetation develops.

The early success of the project can be attributed to the multi-disciplinary project team and the Partnership between the Borough Council and the Environment Agency.

Original Information Providers:
Trevor Odell
Julie Baxter

Completion was celebrated at a launch ceremony in June 2000



1



Restoring Meanders to Straightened Rivers

1.6 River Ravensbourne 2013 Update

Morphological processes are now able to take place on this de-culverted stretch of the Ravensbourne. Erosion and deposition is occurring within the new meandering channel and flow variability has developed. Areas of fast flow are evident in the shallower riffles and there is slower flowing water at the margins where the water level is deeper. Within a month of the works being completed the gravel had been redistributed as expected. The river had exposed the clay subsoil and has now created a stable channel.

Opening up the culvert has reconnected the river to the floodplain. This provides an opportunity for floodwaters to be stored on the floodplain, reducing the flood risk downstream.

The park area is well used by local people for recreational purposes and a site visit and talk was given at a local school following the works.

River Ravensbourne Low energy, gravel

WFD Mitigation measure

Improve floodplain connectivity
Increase in-channel morphological diversity
Preserve and, where possible, restore historic aquatic habitats
Removal of hard bank reinforcement/revetment, or replacement with soft engineering solution
Re-opening existing culverts
Preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian zone

Waterbody ID

GB106039023260

Designation

None

Project specific monitoring

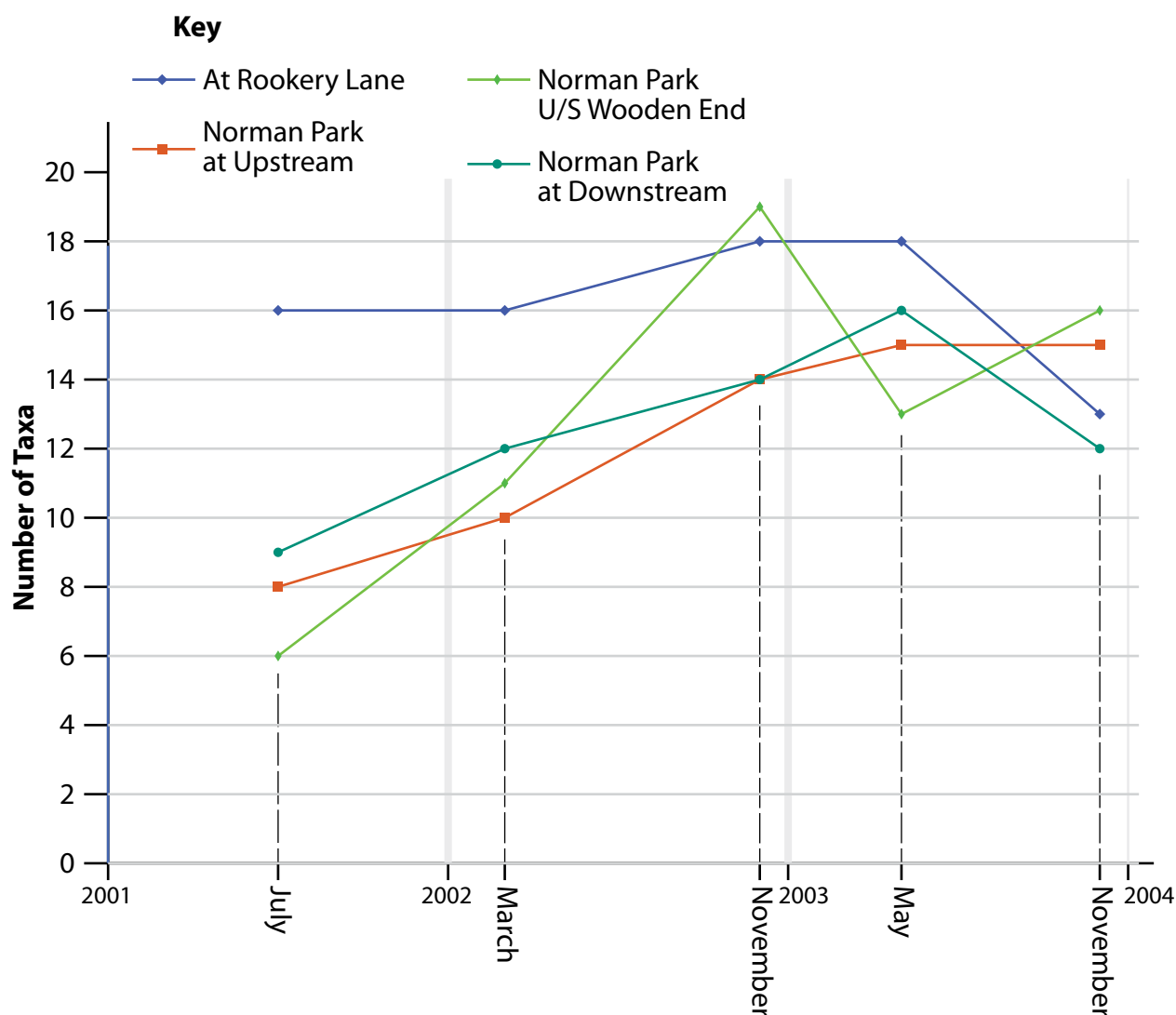
Macroinvertebrate

Effective narrowing of the channel, and asymmetric shallowing of the bed has occurred following restoration – 2012



© Steph Butcher

Macroinvertebrate sampling was undertaken between 2001 and 2003 and this showed an increase in the number of taxa recorded following the works. Further sampling is planned for 2013 in order to compile a more complete dataset.



Changes in the number of invertebrates between 2001 and 2003.

By 2003 numbers for the control site (Rookery Lane) and the restored sites were similar demonstrating ecological improvement in the de-culverted stretch of the river.

(River Ravensbourne, EA data)

Contacts

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Restoring Meanders to Straightened Rivers

1.7 Reconnecting remnant meanders

RIVER LITTLE OUSE

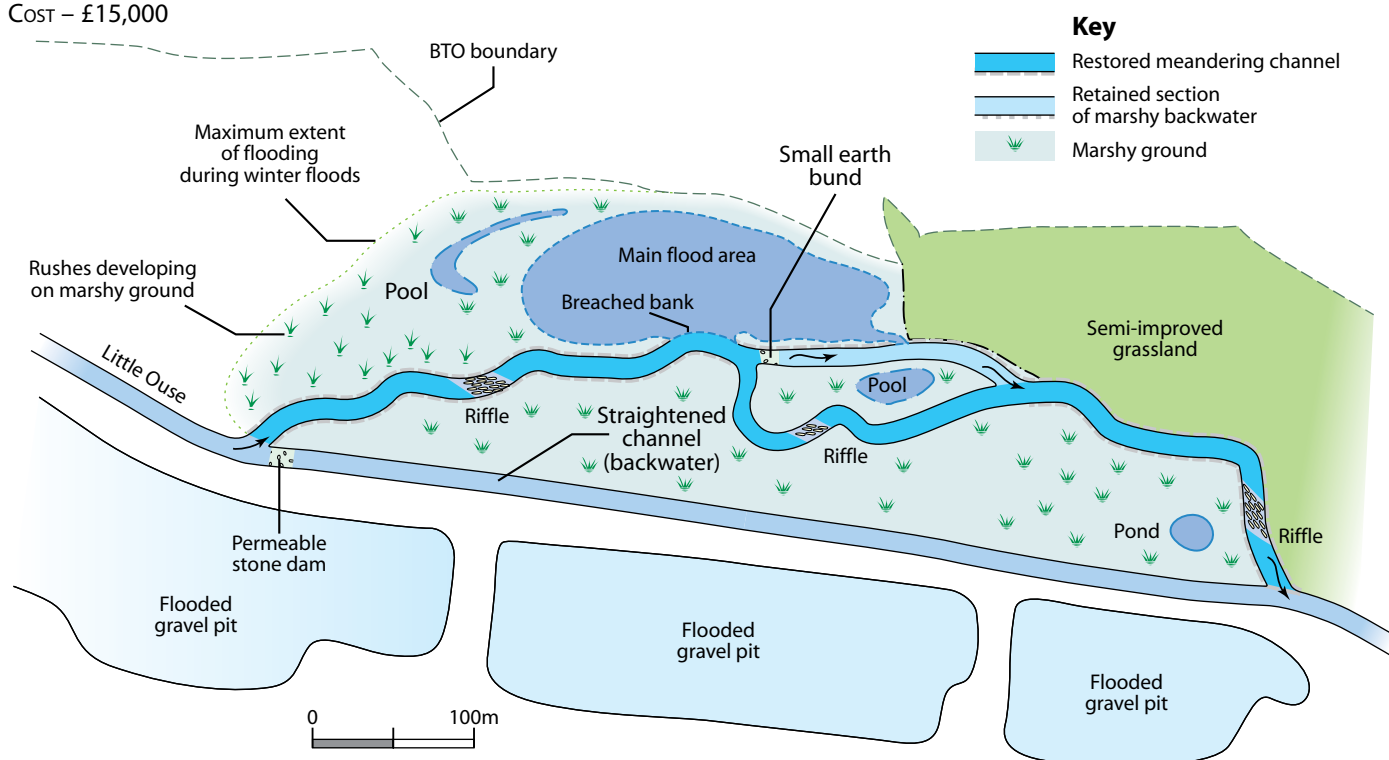
LOCATION - THETFORD, NORFOLK TL870812

DATE OF CONSTRUCTION - 1994

LENGTH - 900m

COST - £15,000

Figure 1.7.1
PLAN OF MEANDERS



Description

The Little Ouse is a low gradient river draining an area of mixed land use (forestry, dry grassland and arable). Sand and gravel extraction has taken place as part of a 30 year programme within the valley. This had led to 900m of the river being bypassed by a new canalised channel.



Canalised course of the Little Ouse

In 1991, the site and adjacent land was purchased by the British Trust for Ornithology (BTO) to create a wetland bird reserve. BTO approached the Environment Agency to assist with restoring flows to the meandering course. The grassland on either side of the old course was beginning to dry out due to the lower water levels within the new channel, and resultant lack of connectivity between river and floodplain.

The new canalised course was straight, trapezoidal, circa 6m wide and 1-2m deep, with 3m dry, steep banks dominated by tall ruderals and grass. In-stream habitat was poor, macrophytes were confined mainly to the shallow margins, and the substrate was dominated by sand with some silt and gravel.

The old meandering channel remained as a damp depression, merely infilled at each end during the excavation of the new cut. By restoring flows to the old channel 900m of diverse river habitat incorporating deep pools, runs and riffles would be regained, in contrast to the uniform, slack and deep water of the canalised section. Additionally, the landowner was keen to see the land adjacent to the meanders flood, restoring the lost hydrological connection between river and floodplain.

Restoring Meanders to Straightened Rivers

1



Looking downstream along the old meanders

The marshy habitat that the isolated meanders provided would be lost through reconnection, so it was decided to retain and bypass a short 120m section of the old course. This would provide a refuge for plants and animals and a source for colonisation of the proposed wetland reserve.

Design

Assessment and design of the restoration scheme was kept simple and carried out 'by eye', since the old channel was still intact as a reedy, damp depression meandering through the valley bottom.

The old course was reopened by excavating the 'plug' material from the upstream and downstream ends of the meanders. Some tree work and minor regrading was carried out along the remaining length of the original course where necessary. The very small amount of spoil was spread within the immediate reach of the excavator. The restored Little Ouse now has an average channel depth and width of 1m and 8m, respectively.

Using a 50 foot (15m) reach dragline, a boulder and stone structure was placed into the river at the upstream end of the canalised reach (permeable stone dam on *Figure 1.7.1*), to raise the river level by 0.6m. This would ensure that approximately 90% of flow would be routed through the re-opened course.



The structure, 6m wide by 10m long by 2m high, was constructed using 1.5m by 1m prefabricated concrete blocks below a 0.75m depth of boulder sized limestone, surfaced with 0.25m of cobble sized limestone. The 'weir' was designed to be permeable to provide a sweetening flow to the canalised channel. Flows, where levels exceed the 2m crest, will overtop and discharge through the retained canalised 'flood relief' backwater channel.

In the middle of the meandering reach a marshy backwater section was isolated with a bund and a sluice at the upstream end to protect the habitat from high velocity flood flows.



Sluice, bund and upstream flooding area

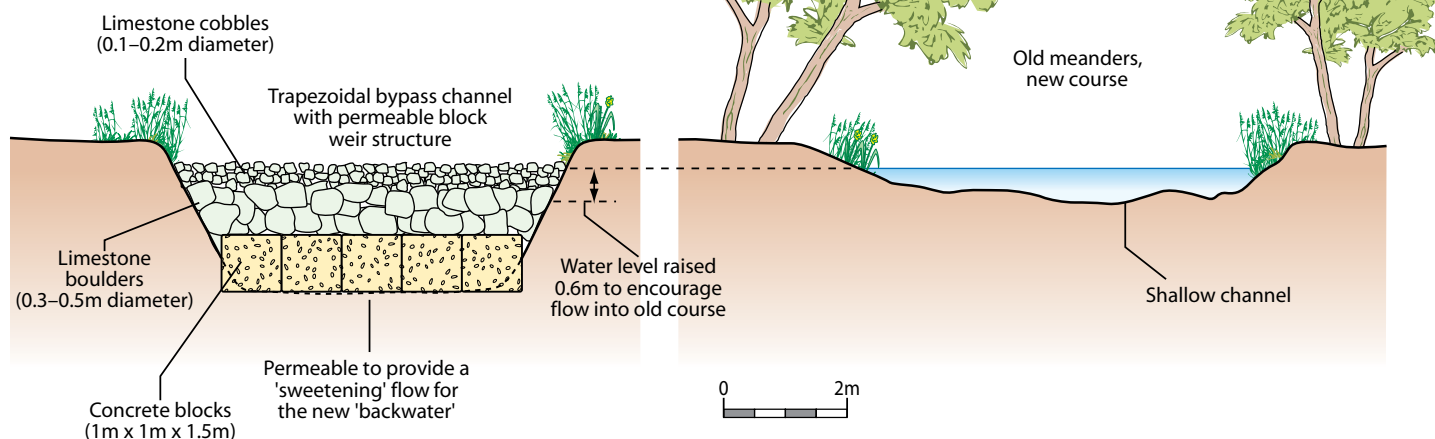


The meanders needed to be 'unplugged' at both ends

Restoring Meanders to Straightened Rivers

Figure 1.7.2

SECTION THROUGH STONE DAM
AND MEANDERS



Subsequent performance 1994 – 2001

Surveys show that the meandering channel is sustaining a diverse aquatic invertebrate community, with stonefly (*Plecoptera spp.*), mayfly (*Ephemeroptera spp.*) and snail (*Gastropoda spp.*) species which are not present in the canalised section. Fish species such as chub (*Squalius cephalus*) and dace (*Leuciscus leuciscus*), also not found in the straight section, are using the reconnected reach as spawning and nursery habitat.

The re-establishment of marshland plants on this site has taken longer than originally anticipated. This may be due to a combination of factors, including an inadequate seed-bank, build-up of silt deposits, and prolonged inundation. However, wildfowl and waders have not been slow to use the greater areas of shallow standing water, including nesting pairs of lapwing (*Vanellus vanellus*).

After reconnection
to the river



Restoring Meanders to Straightened Rivers

1



The restored Little Ouse

Sections of fencing have been erected along the meanders to restrict grazing and poaching by cattle, and to allow marginal plant establishment.

Original Information Providers:
Geraldine Daly
Chris Gregory

Some scour around the weir was discovered, due to overtopping in high flows. The length of the dam and a section immediately upstream has since been revetted to minimise further scour.



Flooding along meanders – Spring 1999



1



1.7 River Little Ouse 2013 Update



© BTO

Main breach along the meanders – 2002



© BTO

Same bank reinforced using blue clay – October 2003



© BTO

Breach of the reinforced clay bank – March 2004

Restoring Meanders to Straightened Rivers

River Little Ouse	Low energy, gravel
WFD Mitigation measure	Improve floodplain connectivity Increase in-channel morphological diversity Preserve and, where possible, restore historic aquatic habitats
Waterbody ID	GB105033043090
Designation	None
Project specific monitoring	Vegetation, Birds, Water level

High river levels resulted in scour of the more vulnerable sections of meanders causing breaches in the banks. These were repaired using clay in 2002, but subsequently failed and further breaches occurred. These were exacerbated by a fallen willow (*Salix* spp.) branch that deflected the flow.

In the context of this project, the original design was aimed at encouraging seasonal inundation on the floodplain to create suitable nesting habitats for waders such as lapwing, as well as providing winter wildfowl refuge. These unpredicted breaches have, instead, resulted in permanently ponded areas.

The increased regularity with which the floodplain is inundated, combined with the topographic variability of the floodplain, means that lower areas now remain permanently wet. At this site this is not acceptable. In other locations however, this could be deemed as providing additional habitats on the floodplain whilst working with natural river and hydrological processes. In addition the project has had positive benefits for the river. In flood flows fine silt is deposited on the floodplain resulting in a clean gravel bed.

Clay bunds and the subsequent implementation of staked-in pre-planted matting and pallets installed to prevent erosion of these highly vulnerable banks have not been successful. In the case of the latter measure, it is possible that cattle poaching exacerbated the destruction of the matting and pallets.

Monitoring of the vegetation has indicated that the banks greater than 0.35m in height have become well vegetated, indicating greater potential stability where overtopping is less frequent (i.e. time between floodplain flood events is designed to allow vegetation to establish). As a result a decision has been made to raise banks slightly from the original design. This is to ensure future over-topping only occurs when banks are stable and not vulnerable to erosion during the flood season. Young willow shrubs will be used to build up the banks to create 'living revetments'. Work will commence in September 2013 at an approximate cost of £6,000.

Restoring Meanders to Straightened Rivers

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Initial vegetation growth
on pre-seeded coir matting
– December 2005

© BTO



Erosion of the coir matting
– April 2008

© BTO

This project demonstrates the need to understand the specific characteristics and vulnerability of your site. Whilst lowering a bank to create a breach for floodplain reconnection is a positive idea, getting the height correct to enable vegetation to establish and create some stability between overtopping events is critical. In addition it has highlighted that monitoring the site can allow you to adaptively manage and enable you to resolve any initial issues.

Contact

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Restoring Meanders to Straightened Rivers

1.8 Restoring a meandering course to a high energy river

ROTTAL BURN

LOCATION – GLEN CLOVA, ANGUS, SCOTLAND NO36936919

DATE OF CONSTRUCTION – TWO PHASES – MAY/JUNE 2012 AND AUGUST 2012

LENGTH – 1,200m

COST – £200,000

Description

The Rottal Burn has a steep catchment of 17.05km² to its confluence with the River South Esk. The final 1km of the Rottal Burn between Rottal Lodge and its confluence with the River South Esk was realigned and straightened soon after the 1830s. In this final reach the steep catchment meets the South Esk glen. This reduces the gradient and results in deposition of bed material. The bed of the channelized burn was continually aggrading and sediment was being deposited at the confluence with the River South Esk. In response, sand, gravel and cobbles had been dredged and used for agricultural embankments (up to 2.2m above field level) to reduce the frequency of flooding of the surrounding fields. In 2003, the stretch was dredged again, destroying the existing habitat.

The River South Esk and its tributaries are designated for Atlantic salmon (*Salmo salar*) and freshwater pearl mussel (*Margaritifera margaritifera*). Although spawning habitat was present in the burn, the lack of variation resulted in low numbers of juvenile salmonids and any fry produced were often washed out of the burn by spate flows. Working with the supportive

Rottal Burn

High energy, gravel

WFD Mitigation measure

Restore form and function (channel and channel migration zone)
Re-connect floodplain (remove or set back embankments)
Make flow regimes more natural

Waterbody ID

5812

Designation

SAC

Project specific monitoring

Fish, Habitat, Macroinvertebrates, Plants, Birds, Morphology

owner of Rottal Estates, the fisheries trust saw an opportunity to improve the availability of fish habitat, and improve the overall habitat, by restoring the burn to a naturally functioning state and reconnecting it with its floodplain. This would support the recovery of sustainable populations of Atlantic salmon, brown trout (*Salmo trutta*) and, in the long term, freshwater pearl mussel (which is dependant on salmonids for the completion of its life cycle).

Council planning permission, a CA Engineering works (Controlled Activities (Scotland) Regulations) licence and a Habitat Regulations Appraisal, due to the site being within a SAC, were all necessary.



Dredged gravel forms an embankment on both banks. The channel runs in a straight line to the confluence with the River South Esk – May 2006

© SNH

Restoring Meanders to Straightened Rivers

1

Design

The scheme was designed to allow natural processes to shape the channel's features, rather than focusing on creating individual habitat areas. The new channel was over-sized compared to the existing straight cut, to allow space for the natural features to develop. It was also anticipated that the burn would actively adjust its course within the wide corridor between the old cut to the north and a knoll and new spoil bunds to the south (Figure 1.8.1).

Figure 1.8.1

MONTAGE SHOWING NEW CHANNEL
AND OLD COURSE—29TH AUGUST 2012.
AERIALS © SEPA

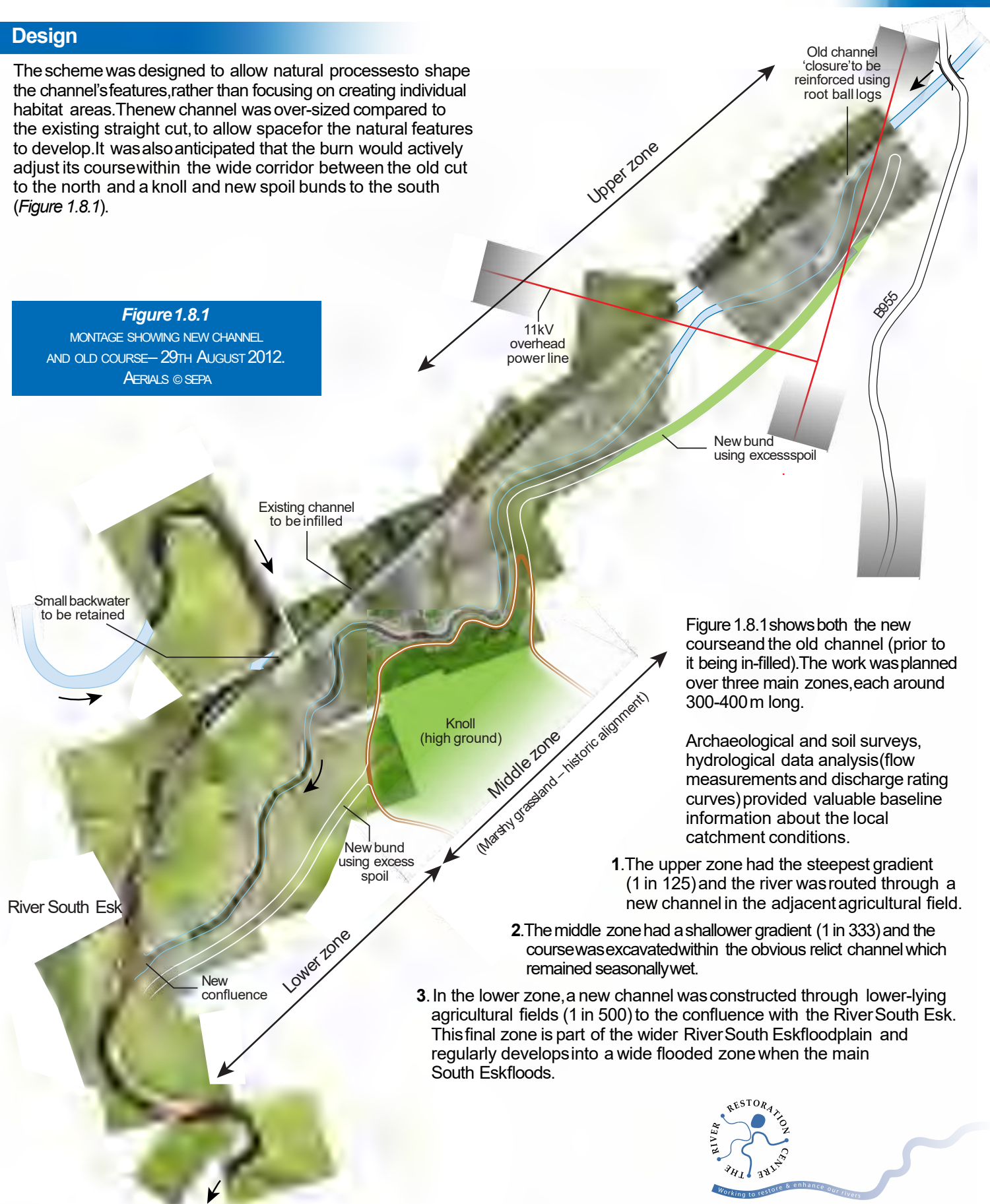


Figure 1.8.1 shows both the new course and the old channel (prior to it being in-filled). The work was planned over three main zones, each around 300-400 m long.

Archaeological and soil surveys, hydrological data analysis (flow measurements and discharge rating curves) provided valuable baseline information about the local catchment conditions.

1. The upper zone had the steepest gradient (1 in 125) and the river was routed through a new channel in the adjacent agricultural field.

2. The middle zone had a shallower gradient (1 in 333) and the course was excavated within the obvious relict channel which remained seasonally wet.

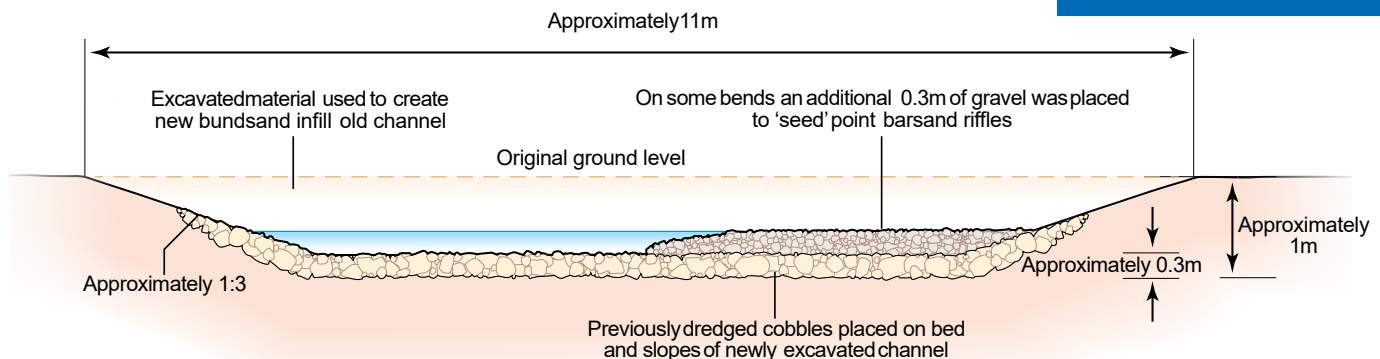
3. In the lower zone, a new channel was constructed through lower-lying agricultural fields (1 in 500) to the confluence with the River South Esk. This final zone is part of the wider River South Esk floodplain and regularly develops into a wide flooded zone when the main South Esk floods.



Restoring Meanders to Straightened Rivers

Figure 1.8.2

TYPICAL CROSSSECTION SHOWING A SIMPLE APPROACH TO THE CHANNEL DESIGN



The initial design concept specified the 45 degree bank angles of the upstream reach, and a varying bed profile at meanders. However, during construction the bank slopes were formed at shallower slopes of 1 in 3. This was to reduce the potential for erosion in the sandy soils and to help vegetation establishment.

In a further change, and working on the principle that the channel would quickly rework its material, the cross section at each meander was formed as a flat profile (similar to the straight runs – Figure 1.8.2). This allowed the bed of the channel to be used as a haul road for placing the gravel substrate. As a result, the channel profile remained relatively similar throughout but with distinct bed gradient changes over the three zones.



© K. MacDougall/Fraser Murdoch

Three panoramas showing the development of the middle reach – 2011 to 2012

Restoring Meanders to Straightened Rivers

1



© K. MacDougall

The newly excavated channel, viewed from the knoll, following the old course – Sept 2012



© RRC

The channel is depositing and moving sediment, creating features – July 2013

Substrate previously dredged from the burn and won from the embankments was placed on the bed and banks of the newly excavated channel to an approximate depth of 0.3m. The median gravel size was 60mm with the range of material being fine sand to large cobbles. In thirteen locations, additional gravel was placed to a height of 0.3m above the surrounding design substrate level (*Figure 1.8.2*). These locations were where features were expected to occur and were intended as source material for natural processes to use to shape the burn.

The steeper upper section of the new channel would be subjected to the greatest erosional pressure, so the design width was increased to accommodate both sediment deposition and discharge.

A two-phase construction programme allowed the new dry channel to be constructed during late spring, with additional time given for vegetation to establish on the banks prior to the final opening.

Initially a downstream 'plug' was retained. However, due to both the site layout and the short window of opportunity for vegetation growth, this was removed and the downstream opened up. At the upstream extent, a pipe was installed between the existing and new channel to provide a small feeder flow to allow bankside and aquatic ecology to develop prior to the entire burn being diverted.

By cutting the new channel through the low lying, rush dominated wetland vegetation, very little vegetation establishment was needed in this middle reach. Careful turf stripping, storage and

replacement helped to speed up the re-vegetation within such a short growing period. In late summer, flow from the existing channel was diverted into the new course.

Fine silt and sand transportation from the site works into the River South Esk was a major concern, with the river's designation for freshwater pearl mussel. Measures taken to mitigate this included straw bale silt trapping and allowing time for vegetation to establish before the new channel was connected.

Excavated spoil was stockpiled and then used to infill and landscape the old channel once it was dry. Excess material was used to create two left bank bunds to prevent out of bank flood flows from outflanking the knoll.

Wind-blown Scots pine from the estate, was used to reinforce areas of possible adjustment such as the initial bend into the new course. In early 2013 the tree planting was completed and a locally sourced riverbank wild grass seed mix was sown.

A number of challenges were faced during the construction including the presence of overhead services, the remote location, inclement weather, and the limited growing season at an altitude of 220m above sea level.





Restoring Meanders to Straightened Rivers

Subsequent performance

The new channel was tested by a number of significant flow events, including a large spate just 36 hours after being diverted. This was followed in mid-October 2012 by one of the largest floods in 10 years.

As predicted, the upper reach has been more morphologically active, with new sediment supplying the formation of gravel bars. There has been some local erosion which has allowed a greater variety in channel width and depth to develop. In the middle reach, sand and gravel bars have formed and connectivity with the adjacent floodplain and wetland area has increased. Erosion has varied significantly depending on the bank material (peat, sand or gravel) showing that accurate prediction of channel adjustment is hard to achieve, and that sufficient space needs to be given to allow change to occur.

Bank erosion and channel adjustment are also leading to the erosion of the new upper bund. The main area to be monitored is close to the power lines. Should any stabilisation be necessary, this would be achieved through addition of further woody material.

The lower reach remains relatively unchanged after one year. This is partly due to the greater distance from the new input of bed material and also as the spate events have all thus far involved a simultaneous rise in both the burn and the main South Esk. This creates a ponded floodplain with low velocities and little energy to shape the lower burn.

A fisheries survey identified 30 salmon redds in the upper reaches of the restored channel, while sea trout and otters (*Lutra lutra*) have also been observed.

A monitoring network has been set up to assess the longer term performance of the project. Pre-work surveys included a fluvial audit, topographic assessment and geomorphic appraisal in addition to baseline fisheries, river habitat, bird, plant and aquatic invertebrate surveys. Post construction monitoring has included repeat topographic and aerial survey from a small remote control helicopter.



© K. MacDougall

The as-dug channel with cobbles from the old dredgings embankment – 2012



© RRC

Subsequent deposition and erosion from, now unconstrained, natural processes – July 2013

Contacts

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Restoring Meanders to Straightened Rivers

1.9 Reconnecting a remnant meander

RIVER ROTHER

LOCATION - PETWORTH, WEST SUSSEX FROM SU98051906

DATE OF CONSTRUCTION - 2004

LENGTH - 850m

COST - £90,000

Description

The 'Shopham Loop' is a large meander bend which is part of the natural course of the Western River Rother.

The Rother was engineered for navigation in the 18th century. At Shopham a large meander bend was bypassed with a straight navigation channel that featured a lock gate at its downstream end. These gates impounded water to a depth of up to two metres, but did not pass any river flow. The flow was side spilled into the loop via a purpose built structure.

River Rother

Medium energy, sand

WFD Mitigation measure

Improve floodplain connectivity
Preserve and, where possible, restore historic aquatic habitats
Preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian zone

Waterbody ID

GB107041012810

Designation

None

Project specific monitoring

Fish, cross sections, fixed point photography, water levels, macroinvertebrates, macrophytes

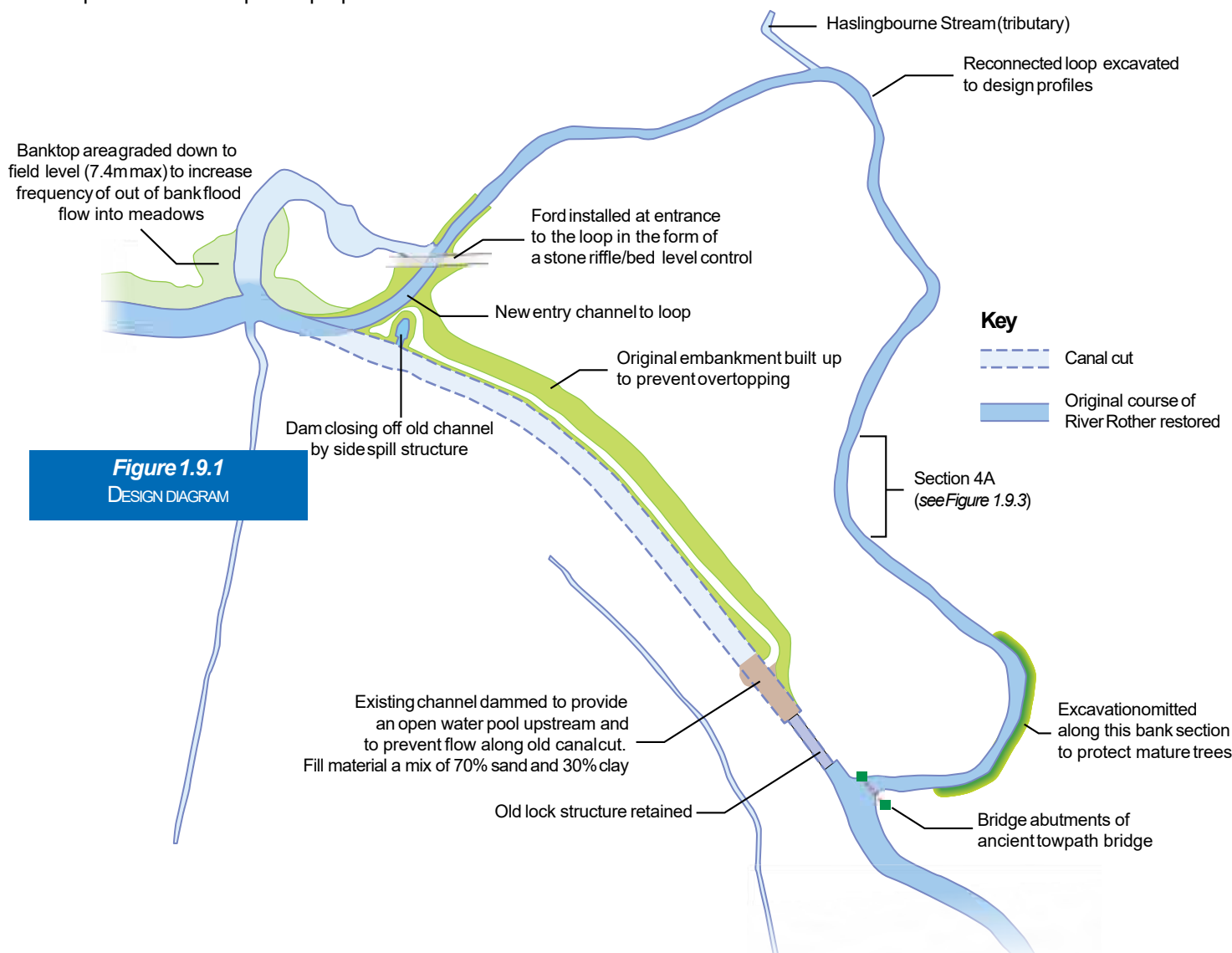


Figure 1.9.1
DESIGN DIAGRAM

Restoring Meanders to Straightened Rivers

1

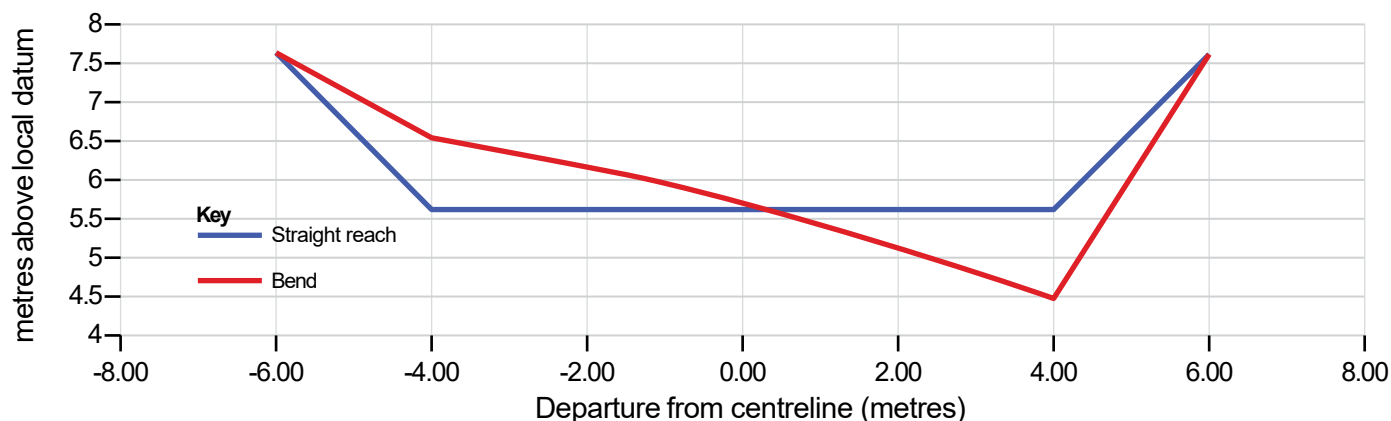


Figure 1.9.2

DESIGN CROSS-SECTIONS FOR STRAIGHT REACH AND BEND APEX

After navigation on the Rother ceased, the lock gates were removed which dropped the river level with flow passing freely down the cut. The side spill structure was also opened up to ensure that at least a part of the river continued to flow along the original course of the meander.

The loop rapidly became blocked with deposits of sand, as the flow velocity fell due to the reduced flow passing into the loop.

Concurrently the cut became enlarged due to bank erosion and the stonework of the old lock was partially washed out by floods. Several attempts were made to keep the old course of the River Rother open, but none was successful.

The project aimed to divert flow back through the meander loop, with a channel capacity that would remain self-cleansing. This would also restore the diversity of habitats associated with a meandering lowland river and increase floodplain connectivity.

Design

The canal cut was never designed to carry the river flow so it was decided to seal it off with an earth bund, just upstream of the old lock. This mimicked the function of the old lock gates. The entire river flow could then be diverted back into the historic course around the loop.

The reference point for the channel restoration design was a survey of the loop carried out in 2002. Additionally, the narrowest cross sections of the main River Rother channel were referenced against the cross sections collected from the loop and compared with channel dimensions sized by a geomorphologist.

The bank top width was determined by on-site observation of two stone abutment walls from an ancient bridge that provided a reliable representation of the historic channel width.



Two ancient stone abutment walls at the exit of the loop indicating the historic channel width – 2004

© RRC



Expert judgement and field observation was supported by a model to inform the more detailed channel design. However it was impractical to excavate the complex shapes optimised by this model. Therefore the loop was excavated to one of two basic cross-section designs, namely bend apices and straight reaches, while points on the transition between them were interpolated (see Figure 1.9.2). The bed level was set to reflect existing conditions in the River Rother at each end of the loop and to improve connectivity with the floodplain during high flow events. A large scrape was excavated to create wading bird habitat and to provide clay for construction of the bund.

In order to prevent undermining of the stone abutment walls (which were of archaeological significance) at the downstream confluence, sheet piling was driven down to bed level across the river and a 'bed check' created from a base layer of coarse locally-sourced sandstone. At the entrance to the loop a ford was created for farm traffic and to serve as another bed check. It too was dressed with gravel to mimic a natural riffle.

A new gravel riffle was also constructed upstream of the site to replace a riffle that had formed in the canal cut, which became obsolete once the cut was sealed off. New gravels totalled £9,000, labour £13,000 and plant hire costs totalled £28,000.

The isolation of the canal cut left a long still water lagoon that provides valuable off river wetland habitat, which helped to achieve the overall biodiversity aims of the project. The old



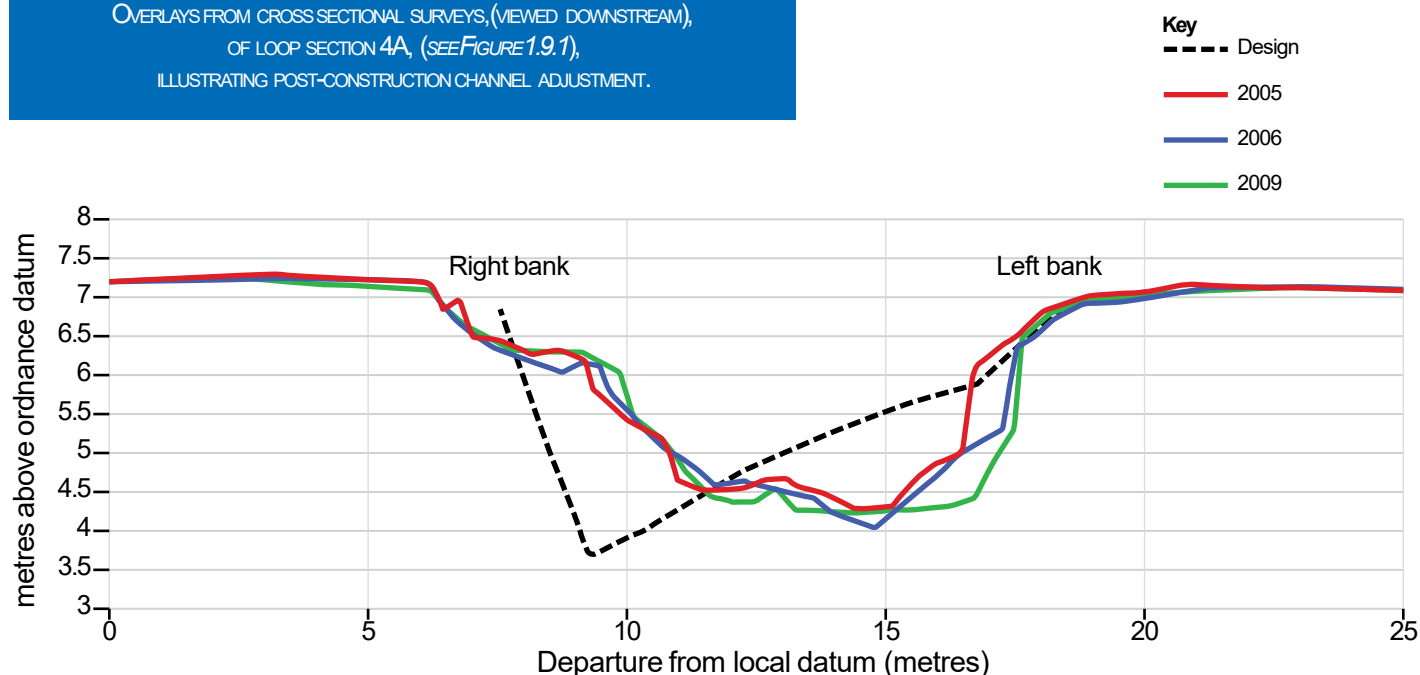
© RRC

Bed check riffle and ford at entrance to the loop post-construction – 2004

canal embankment alongside the cut was repaired and raised above the flood level, ensuring that this habitat would not be washed out by floodwaters. Conversely, the low canal embankments upstream of the loop were taken down to field level to trigger more frequent out-of-bank flows over the adjacent meadows.

Figure 1.9.3

OVERLAYS FROM CROSS SECTIONAL SURVEYS, (VIEWED DOWNSTREAM), OF LOOP SECTION 4A, (SEE FIGURE 1.9.1), ILLUSTRATING POST-CONSTRUCTION CHANNEL ADJUSTMENT.



Restoring Meanders to
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© RRC

Sand in the meander loop
pre-restoration – June 2004

© RRC

Flow in the excavated meander loop
post-restoration – 2005

© RRC

The same meander loop
(three years post works)
– 2007

Subsequent performance

Virtually all of the initial bare banks had established a good cover of vegetation two years post-construction (2006). Mature woody vegetation retained during the project has contributed woody material to the channel, and species diversity of the floodplain has increased significantly, with many bird species regularly utilising the newly created wetlands.

The fish community of the restored loop was consistent with that of the wider Rother catchment. Higher than average populations of bullhead (*Ameiurus nebulosus*), chub (*Leuciscus cephalus*), brown trout (*Salmo trutta*), grayling (*Thymallus thymallus*), sea trout (*Trutta morpha trutta*) and barbel (*Barbus barbus*) have been observed. The stone bed check structures at the upstream and downstream ends of the loop have acted as spawning grounds for many of these fish species.

Monitoring of the site between 2002 and 2009 indicated a positive performance of the technique. Changes were observed in cross-sectional area (see Figure 1.9.3) suggesting a dominance of erosion over deposition in the loop. There was no significant (more than one metre) lateral channel change between autumn 2004 and a survey in 2006, but small-scale channel adjustment has been widespread. Therefore it can be concluded that the pre-restoration issue of sedimentation in the loop has been resolved and that the newly-excavated channel is slowly adjusting to a more natural, and desirable, form.



© RRC

Shopham Loop post-restoration – 2009

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Referencematerial – Click [here](#)





Restoring Meanders to Straightened Rivers

1.10 New meanders replacing a lined urban channel

BRAID BURN

LOCATION - INCH PARK, EDINBURGH NT277711

DATE OF CONSTRUCTION - LATE 2008 – MID 2009

LENGTH - 310M

COST - £110,000

Braid Burn

Medium energy, gravel

WFD Mitigation measure

Restore form and function (channel and channel migration zone)
Remove structure (culvert, bank protection etc)
Make the flow regimes more natural

Waterbody ID

3500

Designation

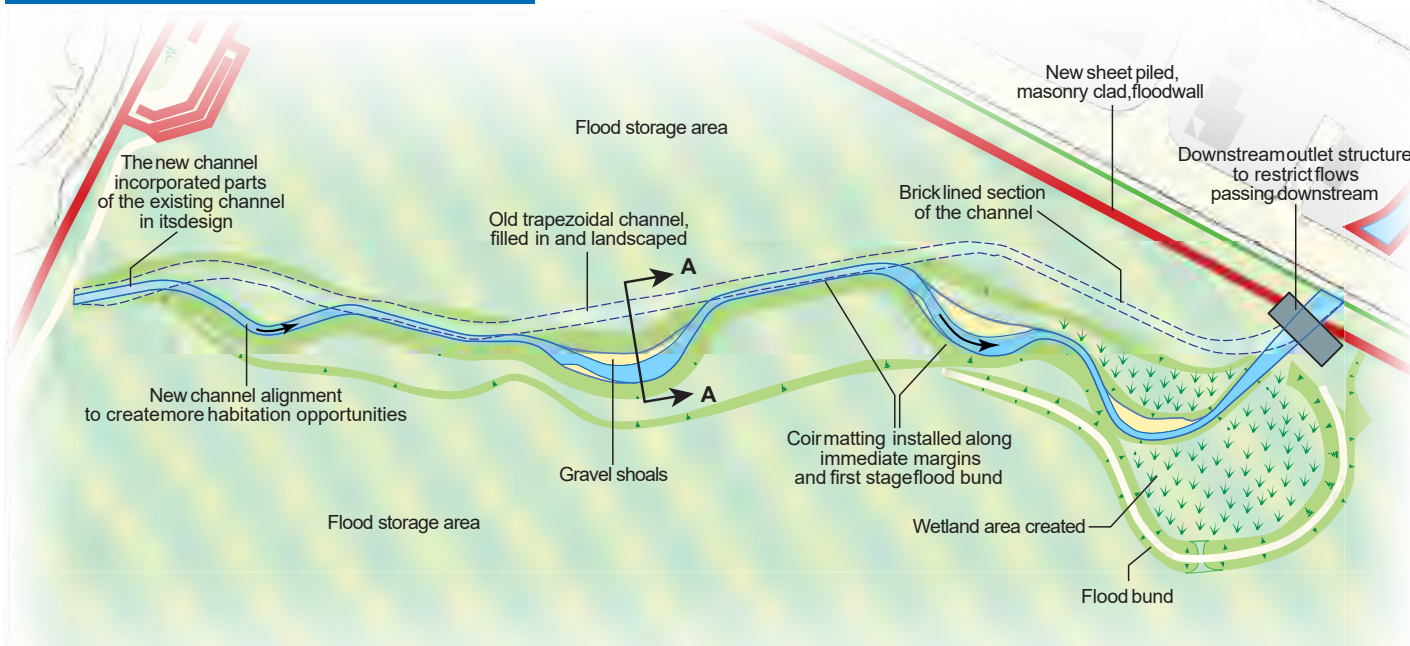
UWS

Project specific

BAP species (pre-only)

Figure 1.10.1

PLANFORM OF THE BRAID BURN THROUGH INCH PARK



The re-meandering of the Braid Burn at Inch Park was a small component of a wider flood alleviation scheme promoted by the City of Edinburgh Council, designed to protect against a 1 in 200 year flood, with additional allowance for climate change. The scheme utilised the flood storage capacity within Inch Park and so provided an opportunity to promote biodiversity and create habitat along the river corridor. The site is an Urban Wildlife Site (UWS) within the Edinburgh Urban Nature Conservation Strategy and delivers parts of Edinburgh's Local Biodiversity Action Plan (BAP) 2010-2015.

Inch Park is a well used recreational resource within the city, adjacent to a large shopping centre, residential properties and a primary school. The park has a mix of mature woodland and individual trees along with amenity grassland and is maintained

by the City of Edinburgh Council. Prior to the works Himalayan balsam (*Impatiens glandulifera*) was widespread along the margins of the burn where it flows through the park. The council carried out an eradication programme during the few years prior to the flood prevention work starting on site.

The aim was to reintroduce diversity in the width, depth, flow rates and appearance of the burn, to allow natural morphological and ecological processes to take place following initial construction. This was achieved by replacing the brick and concrete channels with sinuous meanders, runs, riffles, shoals and gently sloping banks. A new wetland habitat was also created at the downstream end of the burn.

Restoring Meanders to
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Design

Approximately 80% of the restored course was newly dug and 20% was made up of the retained channel, the banks of which were reprofiled.

None of the brick and concrete sections of the existing channel were incorporated into the new design. These were all broken down and in-filled. Densely graded rock (lumpstone) of 0.075m to 0.3m was imported and used to form the riffles and shoals. Gravels for the new channel were recovered and re-used from the sections of the old course which were to be in-filled. It was deemed that over time natural processes would transport substrate, invertebrates and flora to the new sections of the burn. The hydraulic conveyance of the new naturalised course is at least as great as that of the lined channel, ensuring no increase in flood risk upstream.

As a precautionary measure coir matting was pinned in place along the channel margins and the first stage flood bund, to help protect the clay and soil banks until vegetation established.

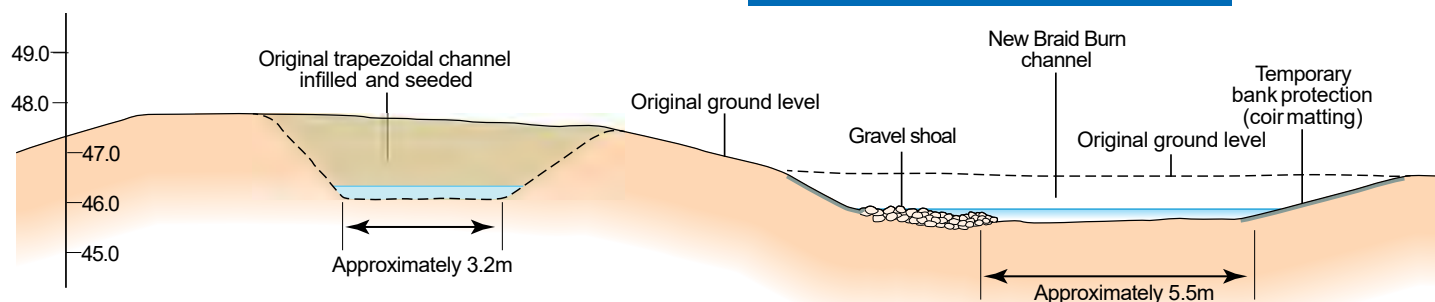


© AECOM

Prior to works part of the channel through Inch Park was brick lined – April 2006

Figure 1.10.2

NEW BRAID BURN CHANNEL AND REPROFILED BANKS
SECTION A-A (SEE FIGURE 1.10.1)



© AECOM

New meander channel cut off-line. 0.075–0.3m lumpstone was used to create the riffle and shoal base to prevent excessive bed scour
– January 2009



1

Restoring Meanders to Straightened Rivers



The gently sloped banks provide additional capacity and promote the natural processes of sediment transport and vegetation colonisation – February 2009

© AECOM

The new meanders were created off-line and, once complete, were connected to the existing channel. Overpumping of some sections of the burn was necessary to maintain flow whilst works were carried out. The downstream end of each meander was opened up first and allowed to fill with water. Each meander was then left for a period to allow sediment to settle and reduce the potential for dirty water to pass downstream. The upstream end was then opened very slowly to control the initial flow through the new meander in order to prevent scouring of loose materials. During construction settlement ponds were created to control and retain muddy water draining from the site.

A debris screen was installed at the downstream outlet structure as part of the flood protection scheme to intercept floating debris and help prevent blockage of downstream culverts. A wetland has been created in a low-lying area adjacent to the outlet. The wetland is covered during higher flows enabling fine sediment and nutrients to be retained.



© AECOM

Wetland area at low flows. The height of the floodwall demonstrates the flood storage capacity within the park – March 2010



© AECOM

Eroded clay forming a stable cascade and adding to the diversity of features within the channel – May 2011

Subsequent performance

Following the works the river corridor is significantly wider, with a sinuous channel and more natural appearance. Riparian vegetation has colonised the banks and wider corridor, which now has a diversity of height, form and texture that was not present prior to the works.

The meanders have increased variability in the width and depth of the channel and have provided flow diversity. As a result a mosaic of habitats has been created for birds, mammals and invertebrates, increasing the overall biodiversity of the immediate area. Of particular note is the presence of otters (*Lutra lutra*) in the watercourse, previously absent from this section of the Braid Burn.

Restoring Meanders to Straightened Rivers

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The shoals around the meanders have trapped significant quantities of fine silt during high water events and vegetation has begun to colonise the sediment, disguising the lumpstone structures. Gravel has been transported out of some parts of the new meanders and replacement with gravel transported from upstream has been slow. At one location a less dense lens of sandy clay within the channel has eroded to form a small cascade and pool.

Informal footpaths have developed along both banks of the burn and are well used. Following the works the burn has become an integral part of Inch Park that brings ecological, aesthetic and recreational benefits to the area. In 2011 the scheme won a commendation for environmentally sustainable construction in the Saltire Society's Civil Engineering Awards.

The coir used to protect the first stage bund from erosion was a fairly dense weave matting which prevented all but the most vigorous species from penetrating. Natural colonisation of the

bund was therefore slow. Coir matting with a more open weave would have allowed more rapid colonisation by a wider range of species. The coir matting used along the immediate margins of the burn worked as designed, quickly becoming covered by sediment.

Environmental Impact Assessment (EIA) ecological surveys (including bat, otter, badger and tree) were carried out before works commenced in order to establish the potential impacts. Routine inspection is carried out by the City of Edinburgh Council to monitor on-going morphological processes and to assess stability. This indicated that the new pool and cascade were stable and as a result this feature was retained. Planting within the meanders captures litter and other debris which passes downstream during high flow events. It is periodically necessary to clear this. Himalayan balsam has been noted following the works and continued invasive species management is being carried out.



© AECOM

The new course of the Braid Burn through Inch Park after two years. Marginal vegetation has established well and natural processes have enhanced the in-channel morphological features that were created – May 2011

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Restoring Meanders to Straightened Rivers

1.11 Returning a woodland stream to its former sinuous course

HIGHLAND WATER AT WARWICKSLADE CUTTING

LOCATION - NEW FOREST, 3km SOUTH WEST OF LYNTHURST, SU273055

DATE OF CONSTRUCTION - AUGUST-NOVEMBER 2009

LENGTH - 2000m

COST - £214,500

Description

Many rivers in the New Forest National Park were improved for grazing by cutting straight drainage channels during the 1850s, resulting in the abandonment of a network of historic woodland streams. These new channels had steeper gradients leading to down cutting and erosion of the underlying sands, gravels and clays.

One example of this degradation is on Highland Water, a small headwater sub-catchment (4.9km²) of the Lymington River. Prior to restoration the channel was up to 1.2m deep and 4m wide restricting the natural seasonal flooding of the surrounding forest. The previously wet woodland and mire habitat had dried out and the increased channel size presented a barrier to the freely roaming forest animals.

Highland Water

WFD Mitigation measure

Medium energy, gravel

Improve floodplain connectivity
Increase in-channel morphological diversity
Preserve and, where possible, restore historic aquatic habitats

Waterbody ID

Designation

GB107042016720

SSSI, SAC, SPA, Ramsar, National Park

Project specific monitoring

Geomorphological surveys, cross and long sections, flow measurements, SSSI condition assessment

The aim of this EU-Life Nature project was to stop the excessive vertical and lateral erosion and to restore the connection between the river and its floodplain. This would be achieved by reinstating the river's natural form and processes. The dual outcomes were to achieve favourable SSSI condition for wet woodland as well as an improvement in WFD status.



© Alaska

The degraded channel was restricting both natural river processes and easy access across the forest for roaming animals – 2009

Restoring Meanders to Straightened Rivers

1

Design

Historical maps were used to identify old or “lost” watercourses to guide the overall restoration design (See Figure 1.11.1). Where they could not be identified, the design was based on expert opinion through field assessment.

The work was carried out in the following stages (See Figure 1.11.2):

Firstly, selected bankside trees on the existing channel were felled in order to create access for machinery. This also had benefits for landscape, aesthetics and ecology, as retaining a straight line of trees would have looked out of place in the forest environment.

Accumulated leaf litter and wood from the existing drainage course was then carefully removed and retained for reuse on site. In places a new channel was dug using an excavator, but only where no obvious channel could be found. The creation of idealised features was avoided, but some areas were more extensively cleared to create deeper pools to maximise gains for fish.

Gravels were transferred from the existing to the restored channel.

Flow was diverted from the existing to the restored channel, section by section (See Figure 1.11.2) from one crossing point to the next moving down the reach. Adopting this phased approach enabled a controlled diversion of the flow into the new channel, reducing the risk of initial channel instability occurring.

The existing drainage course was then in-filled using a mix of 8,000 tonnes of hoggin (as dug sand and gravel mix) and 800 tonnes of firm clay by-product, both sourced locally.

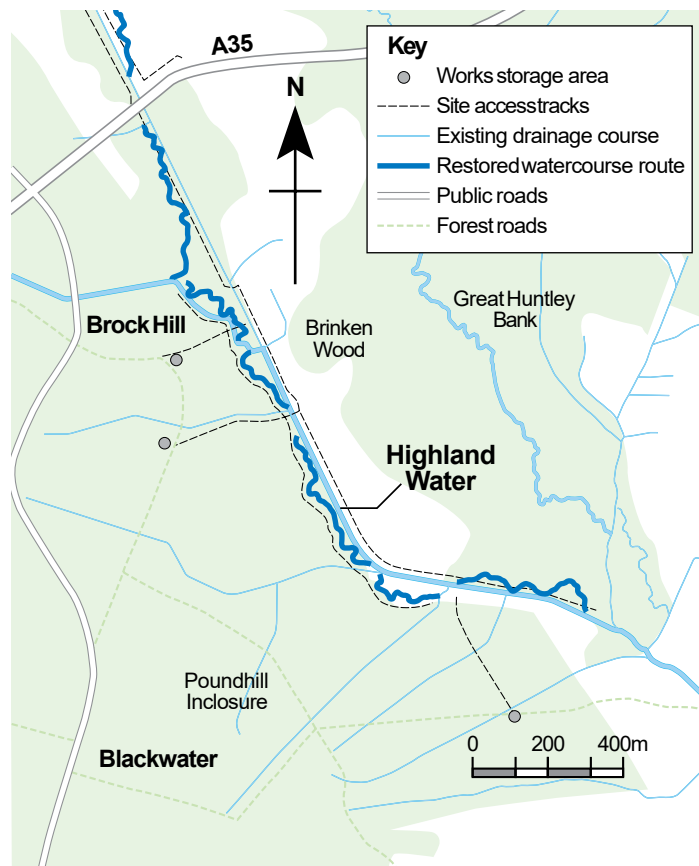


Figure 1.11.1
MAP SHOWING PLAN OF RESTORATION WORKS AT WARWICKSLADE

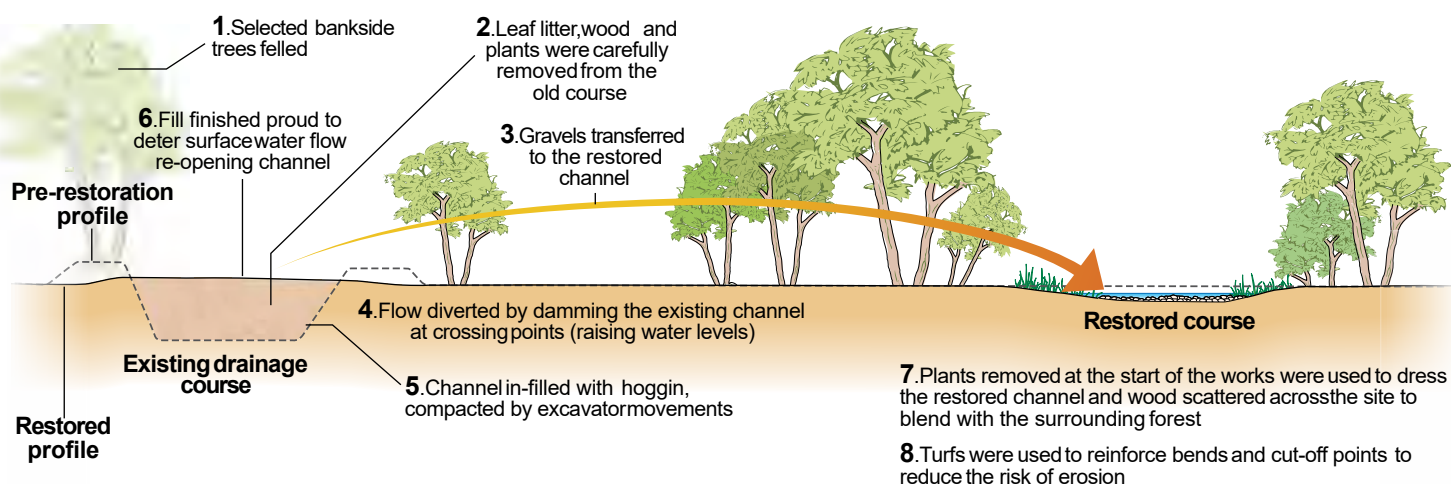


Figure 1.11.2
STAGES OF TECHNIQUE IMPLEMENTATION



1

Restoring Meanders to
Straightened Rivers

The clay was packed tightly at 10m intervals and at construction crossing points to prevent seepage. The rest of the channel length was then in-filled, with excavator movements helping to compact the fill as they moved across the site.

Fill levels were finished slightly above the surrounding ground level to deter any surface water channelling along the fill, which had yet to settle. This could have led to re-opening of the filled channel.

Dead wood was scattered across the site to aid the rapid recovery of the landscape and stop the route becoming a straight path for humans or grazing animals. Turfs removed from the existing course were used to reinforce bends and cut-off points to reduce the risk of erosion immediately post-construction.

Finally the soils, ferns and small plants which had to be removed from the banks during construction were re-used to 'dress' the finished work across the project area.

Sketch design diagrams were developed to provide an overview of the works. However, in this fragile habitat it was essential that the contractor was sensitive to the local conditions, therefore most of the detailed project works decisions were made using on-site expert judgement.



© RRC

Clay infill was tightly packed at crossing points at 10 metre intervals along the channel to prevent seepage – October 2009



© Alaska

Innovative tramway designed to reduce the impact of works on the sensitive forest habitats, especially during wet site conditions – 2009

Restoring Meanders to Straightened Rivers

1

The reduced in-channel capacity of the restored course raised concerns about flooding onto the A35. A pool close to the road was widened to reduce the flood risk in this location, which would have caused major disruption.

An innovative tramway system was devised to enable materials to be moved along the line of the channel, even during poor weather, with no appreciable impact on the heavily designated forest habitat.

Project costs comprised plant hire and labour (£106,500), and infill materials (£108,000).

Critical to the success of this project was the preliminary consultation that took place with stakeholders, in particular the Verderers and Commoners. Initially, fears were raised about the time it would take for the scars of the works to heal, but speed of visual recovery due to the relocation of plants during construction has, as predicted, been rapid.

The work has been well received by the local communities with excellent media coverage. The success of the scheme has facilitated negotiations for future works at other locations across the New Forest.

Subsequent performance

The newly restored channel has been left to develop naturally and no post-construction adaptation has been necessary. A variety of morphological features and in-stream habitats have been re-established and floodplain connection has been restored through more regular bank overtopping. This has helped to re-wet the surrounding woodland habitats. These enhancements have been quantified by a recorded improvement in SSSI condition scores for the area.

The use of high quality infill material was crucial to the success of the scheme. At other locations where a similar technique had been used the redundant channels had been in-filled with poor quality material, which left them vulnerable to erosion and re-opening.



© Alaska

Well-placed shrubs and deadwood blend the old channel into the landscape within days – 2009



© Alaska

Immediately post-construction flow begins to grade materials. Pools and riffles are developing – 2009



© Alaska

The restored course includes both narrow and wide sections – 2009

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Enhancing Redundant River Channels

2.1 Creation of backwaters

RIVER SKERNE

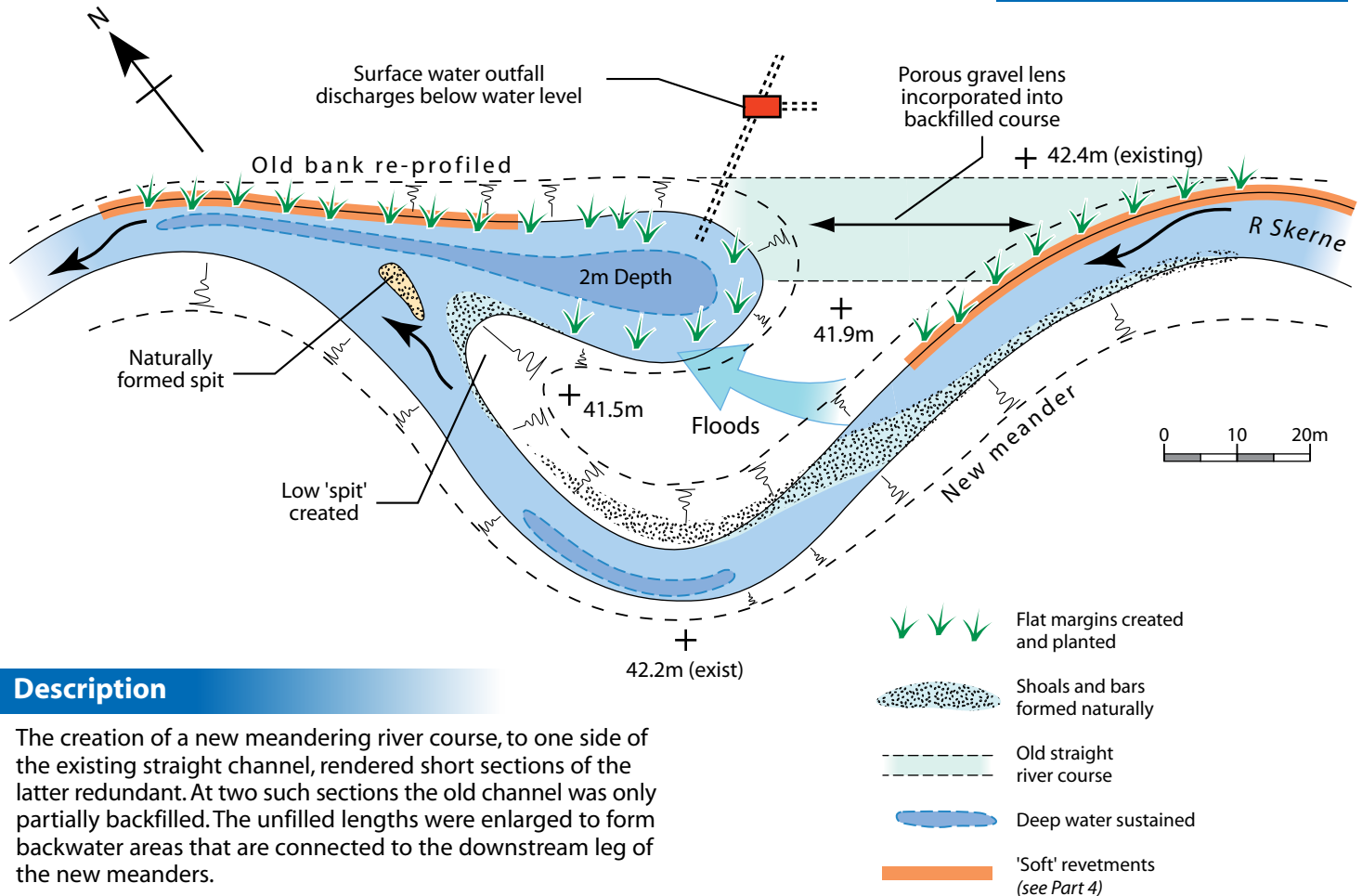
LOCATION - DARLINGTON, Co DURHAM, NZ301160

DATE OF CONSTRUCTION - AUTUMN 1995

COST - £3,000

Figure 2.1.1

PLAN OF BACKWATER AT BEND N2



Description

The creation of a new meandering river course, to one side of the existing straight channel, rendered short sections of the latter redundant. At two such sections the old channel was only partially backfilled. The unfilled lengths were enlarged to form backwater areas that are connected to the downstream leg of the new meanders.

Design

The redundant lengths of channel were trapezoidal in section and needed to be enlarged and reprofiled to achieve their full ecological potential. Both were similarly designed - the largest is shown in *Figure 2.1*.

A normal water depth of 2m was needed in the centre to prevent emergent plants from occupying the whole water area. Conversely, shallow depths around the sides were needed to encourage both marginal and emergent plants. The margins also provide a natural safety buffer against children accidentally reaching deep water.

Development of a series of cross-sections to provide the variable depths led to the plan form shown, which is typically 'onion' shaped. The top width is greatest where the excavation is deepest. The effect is exaggerated further by widening the shallow edges adjacent to the greatest depths.

The hydraulic design of the meander ensures progressive submergence of the backwater during floods. *Figure 2.1* indicates the way in which the land between the backwater and the river channel is profiled to ensure that the downstream leg (and the backwater) submerges before floods flow directly across the meander corridor. Floods sweeping over the backwater flow on downstream, merging with the main river flow. The complex currents that result at this stage affect the patterns of sediment deposition at the junction of the backwater with the main river channel. Large eddies inevitably arise, and these can easily cause sediments to settle out right across the junction, eventually closing it off from the river completely. The floodwater currents passing through the backwater help to reduce this risk; it was anticipated that a shallow spit of sediments would form, but not complete close the backwater. The formation of such a spit was reflected in the profiling of the land at the junction.

Enhancing Redundant River Channels

2

Following excavation and final profiling, the flat shallow ledges were intermittently planted with appropriate species sufficient to encourage their spread. A major surface water outfall was also located within the backwater after reconstruction (see *Technique 9.1*).

A final feature of the backwater is a simulated lens of gravel incorporated into the backfilled original straight channel. Such lenses can occur naturally during the formation of meanders. The purpose of the artificial lens is to encourage a small flow of river water to seep through to the backwater at all times. The amount of flow is dependent upon the difference in water levels between the backwater and the upstream river, which in this location is very small.

Subsequent performance 1995 – 2001

The backwaters are a strikingly successful feature of the project. They not only add to overall visual amenity but attract much bird life because of the diversity of habitats especially at the junctions. People are attracted to the backwater to feed the birds which further encourages them. The eddy currents anticipated are much in evidence, and have led to the natural formation of the small spit highlighted. This is a desirable feature that should help to maintain deep water because of the narrowing effect and increased velocity.



Large Backwater – November 1996



Enhancing Redundant River Channels

2.2 Creation of backwaters

RIVER COLE

LOCATION - COLESHILL, OXON/WILTS BORDER, SU234935

DATE OF CONSTRUCTION - AUTUMN 1995

COST - NO DIRECT COSTS BUT ADDITIONAL SPOIL
CARTED TO LANDFORM AREA

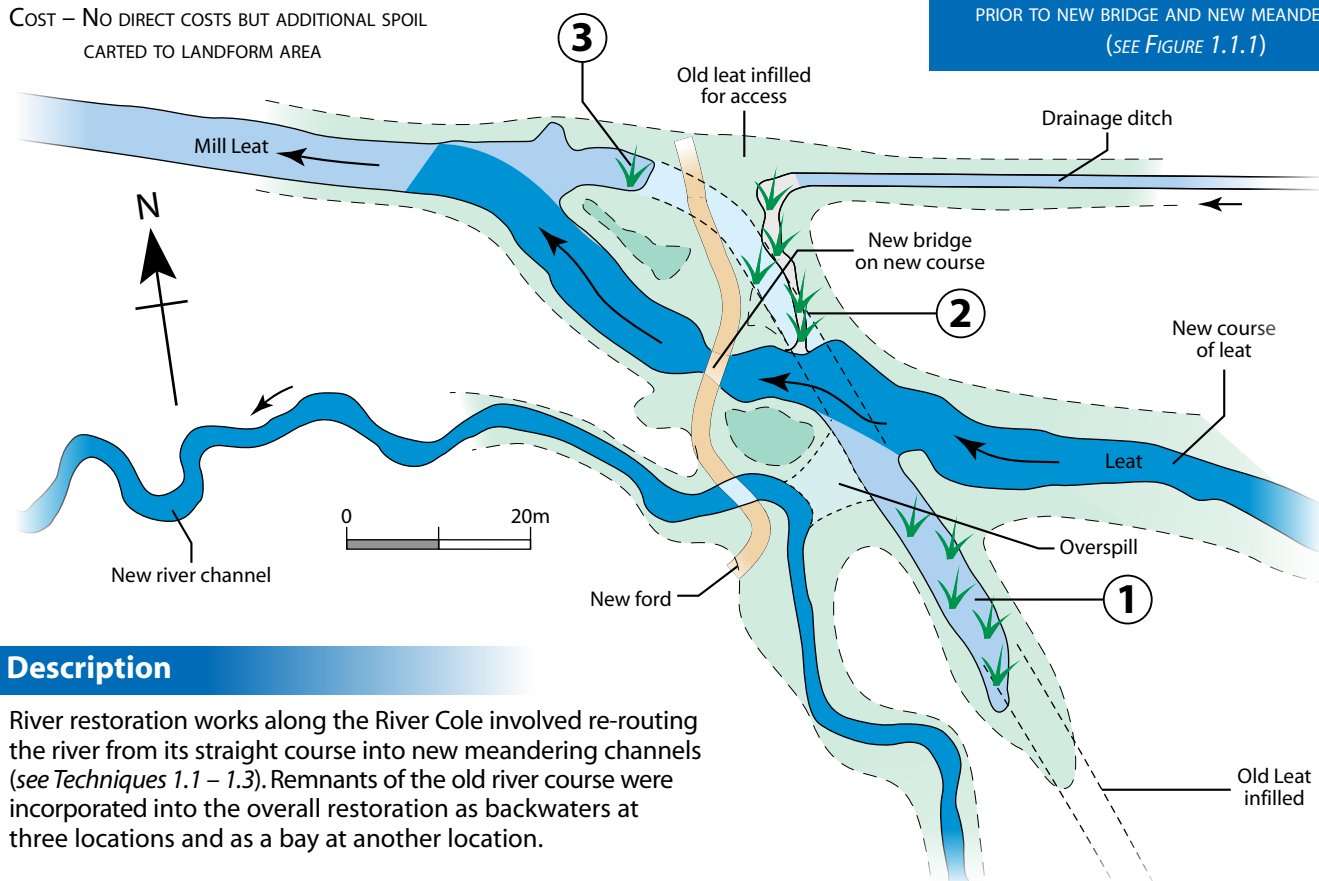


Figure 2.2.1

BACKWATERS AT 1, 2, 3 DELINEATE COURSE OF LEAT PRIOR TO NEW BRIDGE AND NEW MEANDER IN LEAT (SEE FIGURE 1.1.1)

Description

River restoration works along the River Cole involved re-routing the river from its straight course into new meandering channels (see *Techniques 1.1 – 1.3*). Remnants of the old river course were incorporated into the overall restoration as backwaters at three locations and as a bay at another location.

Design

Each feature created is uniquely different, but all are based upon the common principle of only partial backfilling. This also avoids the need torevet or support backfill where it would otherwise abut the new channel.



Backwater 1

Backwaters on mill leat (Figure 2.2.1)

A new bridge was built 'in the dry' before completing the diversion of the leat and backfilling the old course (see *Technique 8.2*). Backfilling was limited to providing a link to the new bridge, leaving the lengths denoted 2 and 3 on the figure open to the river. Backwater 2 is linked to a drainage ditch which backs up with river water when the leat rises, creating a reversal of flow into other parts of the drainage system, which in turn contributes to the seasonal flooding of fields. The bed of this backwater has been raised to just below normal water level to sustain a marshy aquatic habitat. In contrast, backwater 3 remains as open water with marginal ledges and willows.

Backwater 1 was created after excavating a new meander in the leat (see *Figure 1.3*). It is an unfulfilled length of the old leat which was enhanced by removing the embankment from the left side so that rising floodwater could overspill to merge with floodwaters in the new river channel adjacent to it.

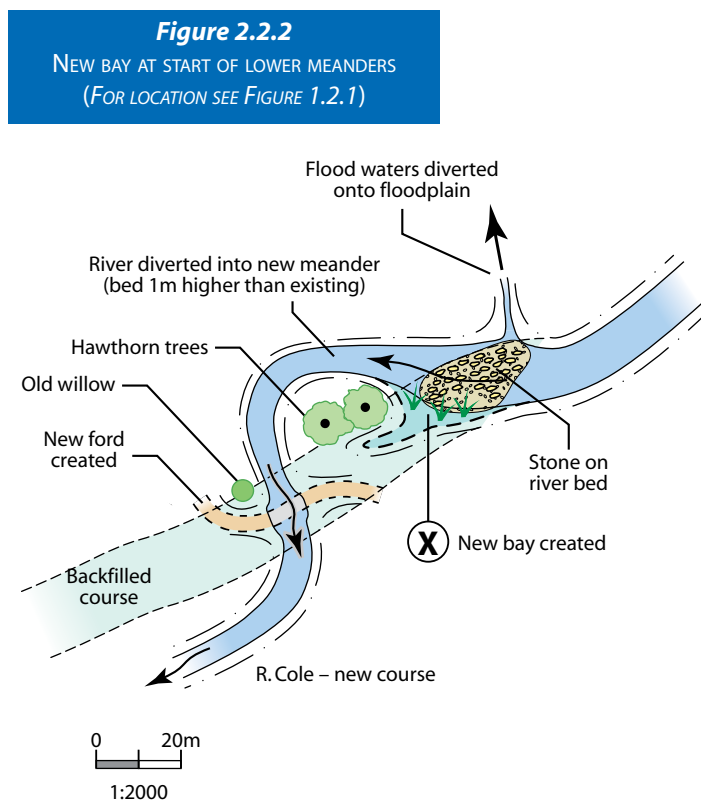
Enhancing Redundant River Channels

2

New bay at start of lower meanders (Figure 2.2.2)

The new meandering channel is smaller than the existing channel upstream and its bed is elevated c.1m higher. As a result, water in the upstream channel is impounded and slow moving which contrasts with a marked increase in velocities within the new channel. The design of the junction of the old and new channels reflects these hydraulic conditions. The risk of downward scour of the new bed was alleviated by backfilling the existing channel bed where it abuts the new and adding a layer of stone to create a secure transition. To complete the diversion, the old channel was backfilled in a manner that created a small marshy bay within which the slower moving floodwaters can eddy freely before entering it. This was preferable to complete backfilling and having torevet the fill to resist erosion.

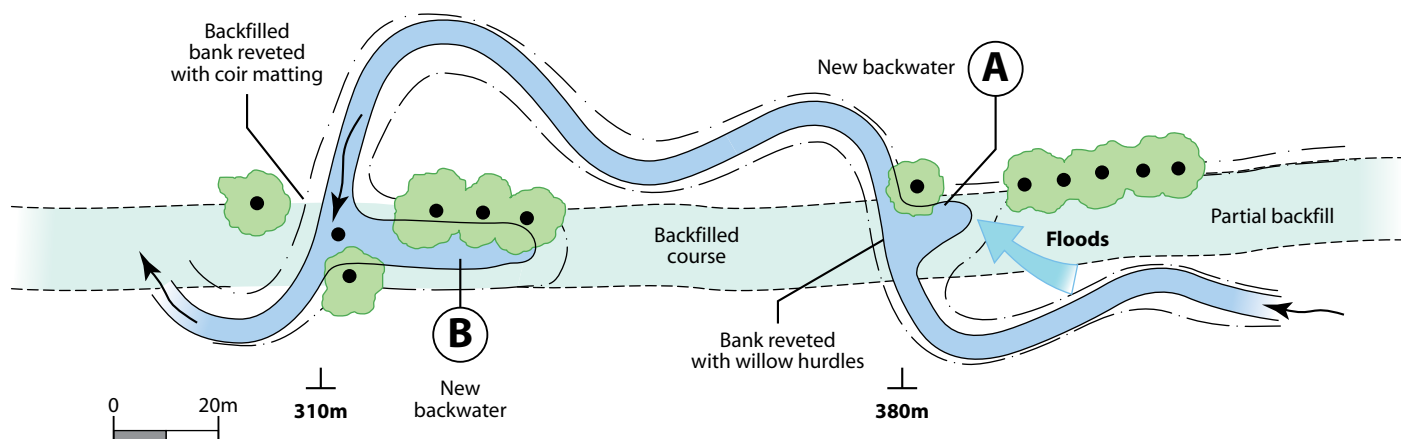
Opposite the bay, an old drainage ditch entered the river. This was incorporated and enlarged to enable floodwaters to pass freely from the river out onto the lowest part of the floodplain, remote from the main river course. As a further safeguard against downward erosion of the new river bed, a stone ford was created 80m downstream where the new channel crosses over the line of the original (see Part 8). This ford acts like a small weir and therefore 'fixes' both bed and normal water levels upstream.



View of shallow bay X



Figure 2.2.3
BACKWATERS ON LOWER MEANDERS AT CH 310M AND 380M
(SEE FIGURE 1.1.1)



Backwaters within lower meanders (Figure 2.2.3)

Two backwaters were created where the new course crosses over the old course. One is much larger than the other, and each is different in nature.

Backwater **A** is located where backfilling of the old channel was kept to a low level so that a valuable line of old river bank trees were not buried. The new river channel approaching the backwater marks the inside of a meander, necessitating further lowering of ground levels, with the result that floodwaters regularly sweep across it to enter the backwater as indicated. This flood flow sustains open water in the backwater as well as shoal deposition, creating varied off-river habitat.

Backwater **B** contrasts with **A** in that the retained trees along the old course all overhang open water and the new channel approaches from behind the trees rather than towards them. The hydraulics are entirely different as a result. The old river bank, behind the trees, remains at a high level preventing any floodwater from passing into the backwater save for small volumes that occasionally pass over the infilled length of channel. The backwater is thus a quiet refuge of still water, and hydraulic interaction with the river is limited to rise and fall of water levels.

The river banks opposite the mouth of each backwater were formed from backfill right up to the new channel profile after infilling of the old river bed. Each was reveted (see *Technique 4.6*).



Small backwater **A**

Enhancing Redundant
River Channels

2

Large backwater **B****Subsequent performance 1995 – 2001**

The new backwaters and bay all add considerably to the overall ecology and landscape amenity of the restored river. Each represents a unique habitat feature created at virtually no direct cost. Savings on the cost of revetment were, however, offset by the need to haul surplus soil to nearby landform areas rather than simply infilling in situ. The value of the features created more than justifies the cost of haulage involved.

